What Catholics Have Done for Science

Rev. M. S. Brennan

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WHAT CATHOLICS HAVE DONE

FOR

SCIENCE.

With Sketches of The Great Catholic Scientists.

BY

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PREFACE.

THE purpose of this little book is, by showing their utter falsity, to refute two wide-spread notions. One of these notions is, that when a man devotes himself to science he must necessarily cease to be a Christian; and the other, that the Catholic Church is hostile to scientific progress.

Nothing, certainly, can be more unjust than the impression that the pursuit of science is prejudicial to a man's piety. A close intimacy with the grand designs of the Creator can only enhance our reverence for His divine beneficence. The more thoroughly we scrutinize the wise and beneficent laws governing the cosmos, the more deeply will we be impressed with the wisdom and goodness of the Almighty Lawgiver. The heart of the true Catholic scientist is instinctively sending up a constant orison to the great White Throne. Gassendi, Picard, Mersenne, De Vico, Piazzi, Boscovich, Leverrier, Tulasne, Haüy, Chevreul, and a host of

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others, traveled as far along the path of Christian perfection as along the way of science.

How the impression that the Church is hostile to science can live among a reading people is truly an enigma. The merit of introducing into scientific study the inductive or true system belongs to the children of the Church. Roger Bacon, Albertus Magnus, and Leonardo da Vinci, the first great masters of the inductive method, dealt its death-blow to the speculative school of Greece.

The children of the Church were the pioneers of every branch of science. The greatest names in Astronomy, Mathematics, Mechanics, Electricity, Galvanism, Chemistry, Optics, Thermotics, Mineralogy, and Botany are Catholic ones. Yes, every branch of modern science owes, not only its origin, but the main part of its growth, to Catholic scientists, so that it can be said with sincerest truth that the scepter of Science belongs to the Church.

Rectory of the Church of
St. Thomas of Aquin, St. Louis, Mo.,
March 17, 1887.

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INTRODUCTION.

THE learned author of the present work being already well known to the reading public needs no new introduction. His natural diffidence, however, forbids his embarking again upon the ocean of current literature without the piloting of at least a brief presentation of the reasons for which he asks an indulgent public to accept this second tribute of his labor in behalf of truth. Requested to introduce, not the author, but his book, "What Catholics have done for Science," we take pleasure in doing so briefly, but none the less sincerely.

We have been told *ad nauseam* that the Catholic Church is the foe of science and a stumbling-block on the highway of progress and civilization. Every treatise in ponderous tome or tiny pamphlet, every public lecture or private debate in which the remotest reference is made to scientific or historic truth, is incomplete, is strangely new in fact, without a matter-of-course allusion to the persecutions by which the Church relentlessly pursues progress. There are to be found even among Catholics some who through negligence or want of opportunity have received but incomplete instruction in their religion, and whose surroundings are malarious with an irreligious atmosphere, and who have been led unconsciously to regard

as truth these slanders which their better judgment should have spurned as patent falsehoods.

Science in its strict sense is defined as "a body of organized knowledge whose phenomena are arranged so as to exhibit the reasons or causes by which they are influenced in their legitimate connection and interdependence."* In other words, science is a classifying of facts. Most of what are called sciences are but bundles of theories, bound together to be untied again by some new discovery. Along the beaten track of progress lie the neglected fragments of foundationless speculations in scientific theories which heads deemed learned, upheld as truth before a pliant and admiring world. That there has been wonderful progress in the domain of physical science during the later centuries we must acknowledge. So deep and fruitful have been the researches, so extensive and satisfactory the observations, that in the future every object would seem possible of accomplishment. Congratulating ourselves upon the marvelous advancement we have made in science, the intoxicating influence of success should not close our eyes to the obligations we are under to those great minds, whose labor and researches have procured for us additional treasures of truth in the vast and mysterious empire of Nature. As the Catholic Church is the stereotyped opponent of all progress, balking all advancement which persecuted *savants* are making in spite of her (so says prejudiced public opinion to-day), it is desirable as well as pleasurable to view in retro-

* Encycl. Brit.

spect the army of eminent men in every branch of science, noting at the same time what Catholics imbued with love for their Church, have done to advance the golden chariot. In the galaxy of discoverers and inventors we find a single name which irreligious scientists as well as obscure historians use as a sort of dummy to represent the Church's opposition to the advancement of truth. This single name, and there is but one—and because of this one instance, volumes of slanderous vituperation have been hurled against the Church—is Galileo Galilei. But for the prominence Galileo's persecution obtained for him, there is little doubt the shade of Kepler would have obscured him. This horrible persecution and imprisonment, which Galileo himself says was the happiest time of his life, is as familiar to the average American child hot-housed in the common schools or burnished in the high-schools as the oft-told story of Washington and his little hatchet, or of Don Quixote and his fierce attack upon the innocent windmill. The best refutation of the slander is Galileo's own description of it.*

When the Church condemns a heresy formally, the world is made aware of it. In regard to Galileo it was deemed wise to restrain his astronomic precocity so that he might hasten slowly along the stellar plane. Kepler, who appeared thirty years before Galileo, was condemned, prosecuted, and persecuted by the Protestant theological faculty of the university of Tübingen for discovering the elliptical form of the

* *Vide Dublin Review*, July 1838; *Rambler*, Jan. 1852.

planetary orbits, thus perfecting the Copernican system, which erroneously advocated the hypothesis of circular orbits. We seldom hear that Kepler fled for his life from Protestant Tübingen to the safety and protection of the Catholic Jesuits of Gratz—but then Kepler was not a Catholic.

To confound the ignorant slanderers of the Church, as well as to edify her devoted children, the present book has been written. There are scientific works which the professed may delve in with profit and delight, but this volume is a lucid and comprehensive glance—panoramic if you will, but none the less satisfactory—into the domain of general science, directing attention particularly to the labor and success which must be credited to the devoted children of that Church which nourished and protected them. The treatise is not argumentative; it is purely explanatory and illustrative; it seems to say to the reader, Behold the fruits! What is to be said of the tree that produced them? These are the children. What of the Mother that bore them? There is a clear-cut ring, a confident familiarity with the various subjects treated, discernible throughout the book. In reading, one unconsciously feels that the writer forcibly abbreviates. In laying down the book we are disposed like an audience at a very interesting entertainment, to protest against its brevity, not because of any incompleteness, but because of its absorbing interest.

JOHN J. HENNESSY,
Rector of St. John's Church.

EASTER MONDAY, 1887,
ST. LOUIS, MO.

What Catholics Have done for Science.

CHAPTER I.

Astronomy.

ASTRONOMY is the greatest and noblest of the sciences. It penetrates the depths of ether, gauges our universe, and counts its myriad stars. It carries us yet beyond the stellar universe, and wafts us to other universes, amid the void nebulæ where new worlds are just forming beneath our gaze. Astronomy studies the most complicated movements of the bodies of our solar system, measures accurately their dimensions and their distances from us, and deduces their masses. It defines the ingredients constituting the sun, the stars, the comets, and the nebulæ. It traces the comets in their eccentric wanderings, declaring the ones to return no more, and fixing the dates of the successive visits of those that do re-

turn. It discovers the laws which regulate celestial movements, and defines the nature of the universal force that sustains the worlds.

It is as good as conceded that the Chaldean shepherds were the first astronomers. They made considerable advancement in practical astronomy. They were able to compute the time and magnitude of eclipses. They discovered the precession of the equinoxes, knew the length of the tropical year, and invented the zodiac.

Hipparchus of Bithynia, who lived a little more than a hundred years before Christ, was the greatest astronomer of antiquity. He invented plane and spherical trigonometry, made a reliable catalogue of 1081 stars, and left very accurate tables of the apparent motions of the sun, moon, and planets. However, the works of Hipparchus have been entirely lost, and we only know of him through his countryman, Ptolemy, who flourished three centuries later.

The Almagest of Ptolemy is a compendium of ancient astronomy, and for fourteen centuries held supreme sway over scientific minds. The distinctive features of the old system of the world, as laid down in this remarkable book, were, that the earth is absolutely immovable in the

centre of universal space, with the heavenly bodies moving around it.

Astronomy flourished for a time among the Arabians, but they adhered closely to the teachings of Ptolemy.

Regiomontanus, who lived towards the close of the fifteenth century, was the greatest astronomer Europe had up to that time produced. He was appointed bishop of Ratisbon by Pope Sixtus IV. Regiomontanus prepared the way for Copernicus, of whom he was for a time the tutor.

All astronomers before Copernicus took the wrong road towards the true solution of the problem of celestial mechanics. Some traveled farther along the path than others, but all journeyed the same way. Copernicus, too, traveled quite a distance along the well-beaten path of error, but his eagle eye at length perceived the absence of the usual landmarks of simplicity and symmetry that nature never fails to post along the highway of truth. Hence, returning to the very beginning, he discovered the right road and journeyed a considerable distance along it. The great glory of Copernicus is to have found out and persevered in the right way.

Copernicus explained very strikingly the differ-

ence between real and apparent motion, showing that the real axial motion of the earth produced an apparent revolution of the whole heavens. He also placed the sun in its proper position as center of our system, classing the earth with the planets, all of which are controlled and governed by the superior force of the great central orb.

The next important figure in astronomy is a gigantic one indeed. Galileo has done more for astronomy than any other man. This extraordinary personage created the science of dynamics, of which astronomy is the most splendid illustration. Galileo first applied the telescope to the study of the heavens, and thus conferred on astronomic science an incalculable advantage. Indeed, it was by that wondrous instrument that the modern science of astronomy has been created. Galileo's discovery of the phases of Venus and the miniature system of Jupiter were irresistible proofs in favor of the new system of Copernicus.

Cassini, to whom the scientific world owes so much, determined the periods of the rotation on their axes of the sun, Venus, Mars, and Jupiter. He solved the problem of astronomic refraction, the effect of which was first recognized by Ptolemy.

Picard furnished a correct unit for astronomic

measurements. Astronomy is indebted to Descartes, the greatest of mathematicians, for the services rendered it by analytical geometry. Piazzi's discovery of the first of the asteroids gave a fresh impetus to observational astronomy.

Le Verrier accomplished the supreme intellectual feat of this century, in tracking the last of the family of planets to his hiding-place on the very confines of the system, and gathering him into the fold.

Spectrum analysis has disclosed to us the physical constitution of the sun and stars. Father Secchi has been the ablest interpreter of this marvellous method of analysis.

In the erection of the noble fabric of modern astronomy there certainly have been master-workmen not of the Catholic faith; and if Catholics have been its designers and chief builders, many non-Catholics, as Herschel, Laplace, and our own Bond, have generously helped to give it sightliness and symmetry. Is it necessary to say that the faith of Copernicus, Galileo, Cassini, Descartes, Picard, Piazzi, Le Verrier, and Secchi has nothing to fear from astronomy?

CHAPTER II.

Nicolas Copernicus.

THE father of the modern system of the world was born on the 19th of February, 1473, at Thorn, in the province of West Prussia. In St. John's Catholic church in his native town there is a beautiful monument erected to his memory; but his great and imperishable monument are the heavens themselves, whose true mechanism he discovered.

He studied at the university of Cracow, where he developed a fondness for mathematics, and particularly its astronomic branch. To perfect himself in astronomy, he went to Rome in his twenty-fifth year, and became a pupil of Regiomontanus, at that time the most renowned astronomer in the world. He received Holy Orders during his stay at Rome, and returning to his own country, was raised to the dignity of canon of the church of Frauenburg, near the mouth of the Vistula.

His observatory was the garret of a small farm-

house, and his instruments of observation were of the rudest workmanship. Copernicus, in his pursuit of astronomical knowledge, struggled under mountainous difficulties, as the telescope had not then been invented, and the law of gravitation and those of motion were entirely unknown. He devoted forty weary years of incessant labor to the establishment of his grand hypothesis. It was not until toward the close of his life and at the earnest entreaty of his friend, Cardinal Schomberg, that Copernicus published his great work "De Revolutionibus Orbium Cœlestium Libri VI.," which he dedicated to Pope Paul III.

Copernicus had a clear, mathematical mind, and acquired a great knowledge of astronomy. He was not satisfied with the ancient system of the world. To his mind it seemed complicated and unsatisfactory. It wanted symmetry and simplicity, whereas the well-known laws which the Creator had given to nature were extremely simple, though grand.

According to the old system the earth was globular and fixed in space, having neither a motion of rotation nor one of translation. The heavens were spherical and revolved completely around the earth once a day. Besides the diurnal motion of the whole heavens, the sun had a proper motion among

the stars, and accomplished a complete circuit in a year. The planets were also said to have a movement among the stars, this being sometimes retrograde and sometimes direct; while at times they apparently lost all motion and seemed stationary. Hipparchus and Ptolemy taught that all heavenly motions were necessarily circular, and, to account for the loop-like paths of the planets, had to introduce a complicated system of eccentrics and epicycles. The planets were represented as moving in circles around fictitious centres, and these centres, again, around the earth.

The teachings of Copernicus may be reduced to two fundamental propositions. One is, that the earth makes a complete revolution on its axis every day, occasioning an apparent diurnal revolution of the heavens. The second is, that the sun, and not the earth, is the centre of motion; and that all the planets, of which the earth is the third in the order of distance, revolve around the central sun.

Copernicus illustrates his first proposition by pointing out various kinds of apparent motion. Sailors on a vessel in smooth water, losing consciousness of their own motion, imagine themselves at rest and the banks and trees moving. The stars are at an infinite distance, and to go around the

earth in so short a space as twenty four hours would demand an infinite velocity. It is much more reasonable to believe that the small earth revolves than that the mighty heavens are impressed with this awful rapidity.

That the apparent annual motion of the sun among the stars could naturally flow from the real annual revolution of the earth around the sun, Copernicus' second proposition, may be easily shown to be the result of the laws of relative motion. As we are carried eastward by the earth's motion of translation, the sun appears to us to move westward with an equal velocity. Day after day the sun appears to go westward among the stars, because we are moving eastward, until in the lapse of a year, the earth having made a complete circuit of the heavens, the sun has apparently accomplished a complete circuit in the opposite direction.

The peculiar motions of the planets are also easily explained on the Copernican theory. In reality, the apparent motion of the fictitious centres already alluded to is due to the real motion of the planet around the sun, and the apparent motion of the planet in the small circle is owing to the real motion of translation of the earth. The earth and all the other planets move around the sun in the

same direction, from west to east. When an outer planet and the earth are on the same side of the sun, they move along together in the same direction towards the east; but the earth moving more rapidly than the planet, gives the latter the appearance of moving backward or towards the west, or of retrograding. When the earth passes beyond the sun, it will then be travelling in the opposite direction to that of the planet, and so the planet will seem to move directly onward with a motion equal to the combined velocities of the earth and planet. If it is an inner planet on our side of the sun, it will move faster than we do, and so will glide along past us; but as it is thrown back on the heavens like to a star, and will appear to us to be on the side of the sun opposite to us, it will seem to go back on its path to meet us, or it apparently retrogrades. When beyond the sun, on the contrary, it will appear to us to have a direct onward motion in its path. In the parts of its orbit where a planet moves towards or recedes directly from us, it appears stationary.

The labors of Copernicus in astronomy were herculean. Primitive as were his means of observation, he arrived at a very accurate conception of the size of our solar system and the relative position

of its members. Assuming the distance from the earth to the sun as unity, Copernicus computed the greatest distances of the other planets from the central orb as follows: Mercury, .405; Venus, .730; Mars, 1.666; Jupiter, 4.980; Saturn, 8.66. These distances as now estimated are: Mercury, .467; Venus, .728; Mars, 1.666; Jupiter, 4.952; and Saturn, 9.00. His figures, after all, are not so very wide of the mark.

Although Copernicus loved his favorite science with the ardor of a devotee, nevertheless he did not neglect the duties of his sacred office. It is said that he divided his day into three parts, devoting one to the calls of his ministry, another to the gratuitous medical care of the poor, and the third to scientific study. In the history of science there is no more beautiful character than Nicolas Copernicus.

CHAPTER III.

Galileo Galilei.

"THE Father of Experimental Science" flourished during the last third of the sixteenth century and the first third of the seventeenth. He was a man of extraordinary mathematical genius, and the greatest experimental philosopher that history knows. Besides his great labors in astronomy and other departments of science, he created that branch of physics known as dynamics.

There is the very highest authority for the statement that Galileo was the inventor of the telescope. It goes without dispute that he was the first to point this wondrous instrument to the heavens. The final establishment of the Copernican system is due to Galileo and his telescope. In fact, just previous to Galileo's discovery of the Jovian system the new hypothesis had begun to fade. Copernicus and Galileo are the two men to whose labors we

owe the modern science of astronomy. Others helped to give it beauty and symmetry, but these were the creators of the science.

The Tuscan optic tube disclosed to the astonished eye of Galileo the most wondrous vision that ever dawned on the sight of mortal man. The silvery face of the moon was distorted into a dark and ragged surface, in which valleys and mountains were easily discernible. The sun's great lustre could no longer hide his pitted face. The brilliant disk, that had been to all antiquity the symbol of perfection, was forced to unmask and disclose to the eye of mortal its contour deformed by hideous spots. Venus, the bright star of evening, which to the unaided vision is but a luminous point, was enlarged into a disk, that at times grew crescent-shaped like the young moon. Jupiter was magnified into a glorious orb with a retinue of moons.

One of the strongest objections to the young hypothesis of Copernicus arose from the absence of phases in Venus. It was urged that, Venus being an inner planet, if it really revolved around the sun it should be gibbous like the moon. But Galileo's telescope radically dissipated this obstacle when it revealed the planet's silvery crescent. The discovery of four satellites revolving around Jupiter

added great strength to the new hypothesis. For here was a miniature of the solar system, four little worlds travelling in separate orbits and controlled by the force of a great central orb.

Galileo, too, first saw the rings of Saturn. The Saturnian system, however, always remained an enigma to him. He could not satisfactorily account for the phenomenon he saw. When first he turned his telescope on the planet, it presented to him a large disk with two arms protruding from the sides. Soon all save the disk disappeared. After a long time the arms again appeared, and soon assumed a crescent shape, and looked as though they had become handles to the planet. Galileo never solved the puzzle. Half a century later Huyghens explained the phenomenon by showing that the planet's seeming appendages were a pair of rings. These rings have a motion which at times carries them directly into the plane of vision, and, owing to the thinness of their rim, are thus rendered invisible. Since the time of Galileo the advancement of astronomy may be said to have kept pace with the improvements in the telescope.

It is curious how small a mole-hill an unfair enemy can magnify into a mountain. The Catholic Church has been accused of persecuting Galileo

because of his science. This accusation is untrue, and therefore unjust. If anything under heavens has ever been worn threadbare, it is this affair of Galileo's inquisitorial tortures. The darkest stain on the name of science is the number of its students, or alleged students, that have basely flaunted this groundless falsehood. Whewell[1] says that Leibnitz, Guizot, Spittler, Eichhorn, Raumer, Ranke, and almost all persons who have studied the facts, have at last done justice to the Church: "That Galileo trifled with authority to which he professed to submit, and was punished for obstinate contumacy, not for heresy."

Catholics claim that an œcumenical council presided over by the Pope is infallible. They also claim that the Pope teaching *ex cathedra* is infallible. No Catholic believes that any priest, bishop, cardinal, body of cardinals, college or congregation, is infallible. No pope teaching *ex cathedra*, nor œcumenical council, censured Galileo. Whewell fairly acquits the Church of persecuting science in Galileo's person, or otherwise.[2] The Congregations of the Index and Inquisition censured Galileo, and commanded him to recite for

[1] History of the Inductive Sciences, p. 535.
[2] Ibid., vol. i., bk. v., ch. iii., sec. 4.

a certain period weekly the seven penitential psalms. Galileo, as a true Catholic, performed his penance.

"This celebrated event," says the erudite Whewell, "must be looked upon rather as a question of decorum than a struggle in which the interests of truth and free inquiry were deeply concerned. The general acceptance of the Copernican system was no longer a matter of doubt. Several persons in the highest positions, including the Pope himself, looked upon the doctrine with favorable eyes, and had shown their interest in Galileo and his discoveries." Galileo had his weaknesses and sins, but, living and dying, professed his unshaken faith in the Church.

CHAPTER IV.

Le Verrier.

HE discovery of Neptune by Le Verrier was one of the most extraordinary achievements of human genius. To this Catholic savant of France must be accorded the first place among mathematical astronomers.

The great principle of gravitation governs all the matter in the universe. Matter attracts in proportion to its mass, and inversely as the square of its distance from the attracted body. Accordingly, each planet of our system is not only affected by the sun, but also by every other planet. So that, in determining the orbit of a planet, the effect upon it of all its neighbors must be considered. When the orbit of Uranus, the great planet accidentally discovered by William Herschel in 1781, was calculated, subject to the perturbations of Jupiter and Saturn, the theoretic path did not correspond with the observed one. There was a very marked discrepancy between them. The only way

in which astronomers could reconcile the matter was by supposing the existence of a still undiscovered large body. And to find this unknown disturber was well understood to be a problem of unparalleled difficulty. Professor Airy, at that time a great astronomer and afterwards Astronomer Royal of Great Britain, pronounced the problem hopeless. "If it were certain," he wrote, "that there was any extraneous action upon Uranus, I doubt much the possibility of determining the place of the planet which produced it. I am sure it could not be done till the nature of the irregularity was well determined from several successive revolutions." This would be a period of centuries.

It is one of the most complicated, as it is one of the grandest, problems in astronomy, to compute a planet's orbit when we know its mass and the masses and places of all the disturbing elements. But certainly the difficulty of the problem is much enhanced when it is required to ascertain the mass and place of an unknown planet that produces a given amount of irregularity in the movements of a known planet.

In 1845 Arago requested Le Verrier, a young but very distinguished mathematician, to undertake the solution of the problem. Le Verrier ac-

cordingly studied the planet Uranus thoroughly. He computed with the greatest precision its path, subject to all the known influences. He compared this theoretic with its actual path as observed in the heavens. He thus accurately determined the nature and amount of its irregularities, and thence proceeded to figure out the size and the place of a body that would be capable of occasioning these perturbations. Success crowned his labors. He calculated that the new planet's place in the heavens on the 23d of September, 1847, should be in longitude 324° 58′, that its appearance should be that of an eighth-magnitude star, and that it should have a visible disk of three seconds.

On the evening of September 23d, Dr. Galle of the Berlin observatory, by request of Le Verrier, sought for the planet. The Doctor turned one of the largest of European telescopes in the direction indicated by Le Verrier, and found the planet within one degree of the computed point, or in longitude 325° 52′. It also appeared, according to prediction, as a star of the eighth magnitude, and having a disk of nearly three seconds. The feat was so very brilliant and unusual that it fairly astounded the whole of Europe. The highest honors were lavished on Le Verrier. He was im-

mediately created an officer of the Legion of Honor. Indeed France, England, Russia, Denmark, and other countries fairly heaped honors upon him. Le Verrier was a very great mathematician, and solved many difficult problems in celestial mechanics.

The attraction of the earth is a feature in the formation of the orbit of Mars. Le Verrier computed the distance between the earth and the sun from the effect of the earth's attraction on the path of Mars. He first calculated the mass of the earth from its influence on Mars. The place which Mars would occupy in the heavens at any time if the earth were absent can be computed, and the actual place may be found by observation. This variation between observation and calculation demands a certain mass in the earth. Having the earth's mass, Le Verrier easily computed its distance from the sun, there being a certain fixed relation between the mass of the earth and its distance from the central orb. The sun's parallax is proportioned to the cube root of the mass of the earth.

The planet Mercury has a very eccentric orbit, and its proximity to the sun renders its satisfactory observation a difficult matter indeed. For these two reasons, astronomers have found the weighing

of this planet far from easy. Le Verrier devised a method of determining the planet's weight, from the perturbing influence of its gravitation upon the earth. He found that the weight of the planet is about the fifteenth part of that of the earth.

Le Verrier's contributions to astronomy were of the highest order. Besides being a profound astronomer he was a pious Catholic, and was as devoted to his crucifix as to his telescope.

CHAPTER V.

Father Peter Angelo Secchi.

FATHER SECCHI, the greatest student of the sun that ever lived, was a member of the great Society of Jesus, that has done so very much for the advancement of science. His great work on the sun is a priceless treasure to the astronomer.

Secchi's views on the radiant orb are in epitome the following: The sun is composed principally of three parts, the nucleus, or body, and two envelopes. The whole mass is in a high state of incandescence, possessing an enormous temperature. The body, or interior of the sun, is gaseous, but endowed with great viscosity. Very many of the metals known to us, and some entirely unknown substances, all enormously heated, compose the sun's nucleus, or interior.

The envelope immediately following the nucleus is called the photosphere, and consists of the metals found in the body of the sun, raised to a high

gaseous state. The photosphere is quite extensive, its limits being fixed, as in the case of all incandescent gases, by the force of gravity of the interior mass, and the temperature of the outer layer reduced by its free radiation into space.

The outer envelope is called the chromosphere, and is very tenuous indeed. The chromosphere is chiefly composed of hydrogen, slightly mixed with a substance unknown on earth, called helium, and another much rarer body, also unknown, and which rises to a far greater elevation than the hydrogen.

The corona, or thin luminous veil surrounding the sun to an immense distance, and distinctly visible during total eclipses, is a continuation of the sun's atmosphere, with which latter even the zodiacal light is, in some as yet inconceivable manner, connected.

The interior of the sun is in a constant condition of the most frightful agitation and turmoil, owing to its enormous temperature and the affinity of the elements for each other. Great eruptions and explosions are continually taking place, by which immense volumes of metallic gases are driven up through the chromosphere. These metallic gases, especially those of sodium and magnesium, which metals have the rarest vapors, are expelled to great

heights, and fall back by the force of gravity in parabolic jets. The returning jets of cooled and condensed vapors produce great rifts or caverns in the bright photosphere, which appear to us as black spots. This is the origin of sun-spots. Sun-spots are not found beyond thirty degrees at each side of the equator. This band of sixty degrees is, therefore, supposed to be the region of greatest activity in the radiant globe. The sun is thought to have an internal circulation, or vortical motion, which sets from the equator to the poles. The activity of the sun's interior is indicated by the apparition of a greater or less number of spots. As to number and size, the spots have a periodicity of about eleven and one-third years. The solar activity increases more rapidly than it decreases. It increases during four and decreases during seven years. These storms in the sun have an electric influence on the earth. A sudden and violent outburst in the sun produces terrific electric storms on the earth.

The origin of the sun's heat is due to gravitation. The diameter of the sun regularly contracts under its own gravity. A contracting body of gas creates heat. Secchi places the intensity of the sun's heat on its own surface at 6,100,000 degrees Centigrade.

Father Secchi was a most industrious student of

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spectrum analysis, the new chemistry that unfolds to us the constituents of the stars. The spectroscope decomposes white light into its component parts. Each metal or other element has its peculiar spectrum. Every metal when incandescent has a characteristic color. For instance, the metal strontium has a splendid red, sodium a yellow, and magnesium a brilliant white light. And each of the metals has its well-known place in the spectroscope. So that any student of the spectroscope knows where to find the iron line, the sodium and other lines. In the spectrum of the sun many of the well-known metallic lines are absent, and their places occupied by dark lines. Those metals whose characteristic lines are missing from the solar spectrum are present in the sun and in the sun's atmosphere. The light of a metal present in the sun is absorbed by the vapor of the same metal in the sun's atmosphere, and so the metal's characteristic line is eliminated from the solar spectrum and replaced by a black line. The stars are suns, and this same principle is applicable to them.

Secchi analyzed the spectra of above six hundred fixed stars. He found, in the main, the stars to be similarly constituted to our sun, consisting of an incandescent nucleus enveloped by an absorptive

gaseous atmosphere of lower temperature. He classified the stellar spectra into four types. The first type comprises stars that are intensely white, such as Sirius and Vega. In the spectra of these the hydrogen line is very strong, but the sodium and magnesium lines are also visible. These stars seem to be very highly heated. The second type comprises yellow stars, such as Arcturus and Capella, whose spectra closely resemble that of our sun.

The third type is composed of the bright red stars, as illustrated in Betelgueze and Antares. The hydrogen lines are absent from these spectra. The fourth type is composed of the telescopic red stars. Of the stars examined by Secchi, 164 are of the first, 140 of the second, and the remainder of the third and fourth types.

On February 26, 1878, closed the earthly life of one of the most useful astronomers and physicists that ever lived.

CHAPTER VI.

Other Catholic Astronomers.

BBOT GASSENDI, "the greatest philosopher among scholars and the greatest scholar among philosophers," who flourished in the first half of the seventeenth century, was an illustrious astronomer. Gassendi was the first to endeavor to bring the eccentric comet within the reach of science. He demonstrated that the cometary bodies were without our atmosphere, and that they really presaged no evil to mankind.

Gassendi was the first to observe the transit of a planet across the sun's disk. Mercury was chosen, and the method he adopted for viewing its passage was primitive indeed, and yet most ingenious. The rays from the sun were permitted to enter a darkened room through a hole in a shutter. A lens formed an image of the sun on a white screen. With the aid of an assistant in a room beneath and to whom the abbot signalled the beginning of the

transit by stamping on the floor, the time of the planet's appearance and the sun's altitude were accurately noted.

Piazzi, the discoverer of Ceres and the preparer of the first great standard catalogue of stars, was a Theatine monk. Piazzi was one of the most laborious astronomers that ever lived, and his catalogue of 7646 stars has been the basis of all star catalogues published since. He made valuable corrections in regard to the parallaxes of some of the heavenly bodies, the obliquity of the Ecliptic, and the aberration of light.

His search for Ceres, the first-discovered asteroid, has scarcely a parallel in astronomic industry. Owing to the great distance between the orbits of Mars and Jupiter, it was thought that a planet should tenant the intervening void. The distances between the orbits of all the other planets seemed to be regulated by a certain order. The only apparent exception was the space dividing Mars from Jupiter. Astronomers began looking for the supposed lost planet, and Piazzi among others. He resolved to examine all the stars in the whole field of the heavens bordering on the Ecliptic. He examined a group of fifty stars at a time. He examined each group four times in succession before undertaking

a new group. The thirteenth star in the one hundred and fifty-ninth group was found to be a small planet or planetoid. It was in the constellation Taurus, in the pure skies of Palermo, the keen-eyed monk saw the first-born of the asteroids, no bigger than an eighth-magnitude star. The finding of this little body had a most wonderful influence on the progress of astronomy.

Jean Picard, a French ecclesiastic, was one of the original members and the first president of the Academy of Sciences. The greatest service he did for astronomy was to make the first accurate measurement of a degree of the meridian. It was this measure of Picard's that enabled Newton to establish the great principle of universal gravitation. When Newton first conceived the idea of the earth's gravitation, he endeavored to see if its influence extended to the moon. He found that, owing to the moon's motion around the earth, she fell from a tangent through a space of 13 feet every minute. He knew that a body at the earth's surface fell $16\frac{1}{12}$ feet in one second. Supposing the attractive force of the earth to be inversely as the square of the distance, he calculated that a body at the moon's distance under the earth's gravity should fall 15 feet in a minute. Unable to reconcile this

discrepancy, he gave up for many years his law of gravitation. But when Picard, in 1670, found that the precise measure of a degree was much larger than the common estimate, and, by consequence, the magnitude of the earth much greater than hitherto considered, the distance to the moon, which was based on the earth's radius, had also to be lengthened. When Newton used Picard's measure, he found his law of gravitation to be absolutely established at the distance of the moon. Picard was the first to draw the attention of astronomers to the phenomena of nutation and aberration.

The Italian Jesuit, De Vico, was a very great astronomer. He calculated the time of the return of Halley's comet, which was looked for in 1835; and was the first to see it on August 5th of that year. He was an indefatigable observer, and is credited with the discovery of eight comets.

Domenico Cassini was in his own time the most renowned astronomer in the world. He calculated the periods of the revolution of the sun, Venus, Mars, and Jupiter on their axes. His tables of the sun, published in 1656, were very accurate. Cas-

sini was the discoverer of the first, second, third, and fifth satellites of Saturn.

Certainly, Catholic Italy rejoices in her full share of renowned astronomical names. To those already mentioned must be joined the great ones of Boscovich, Maraldi, Castelli, and Bianchini.

CHAPTER VII.

Chronology.

UR present almost perfect system of chronology is the fruit of very great labor and struggle. Chronology is the science of regularly dividing time. To measure time, as well as weight and distance, we must have a standard. This standard should be invariable; if possible, absolutely fixed. For the purposes of civil life, two units for the measurement of time have been forced upon us, the solar day and the tropical year. These are natural units of time, and all the troubles of the calendar have sprung from their incommensurability.

The sidereal day is the time it takes the earth to revolve on its axis relatively to a fixed star. It is the absolute length of a revolution, and therefore the actual measure of a day, and consists of 23 hours and 56 minutes. A solar day is the interval of time which elapses between two successive pas-

sages of the sun over the meridian. The solar day is about four minutes longer than the sidereal. The difference is occasioned by the earth's motion of translation round the sun. Whilst the earth is turning on its axis, it is pushing on in its orbit at the rate of 19 miles a second. If the earth had remained fixed in space, the sun and stars would reappear at the same time in the meridian, and the sidereal would have been of the same length as the solar day. But the earth is not fixed; she has travelled onward to another point. The star, because it is situated at an infinite distance, is again found, after a complete rotation, in the meridian; but the sun, its distance being appreciable, is thrown a little out of position, and the earth must turn through a space of four minutes to bring the sun to the meridian. The mean solar day is the standard unit, and it is invariable. It has not varied the hundredth of a second within historic times.

The length of the mean tropical year, however, varies slightly. It is now 4.21 seconds shorter than in the time of Hipparchus. This change is occasioned by the path of the sun being oblique to the equator; and the consequent tendency of the sun to draw the equator after it causes the ecliptic and equator to meet a little earlier each year. This

variation, however, is so very trivial, that in civil service reckoning it produces no practical mischief. The sidereal year is the time the earth requires to make a complete revolution of its orbit relatively to the fixed stars. The tropical or solar year is the time the earth occupies in making a revolution of its orbit relatively to the sun. As the recurrence of the seasons depends on the tropical year, it is the one that is used for the purpose of civil reckoning. Its length is 365 days, 5 hours, 48 minutes, and 46 seconds. Thus the units are sufficiently invariable; the trouble, as already stated, arises from their incommensurability. Everything would be right if there were an exact number of days in a year.

The precise length of the tropical year is 365 days, 5 hours, 48 minutes, and 46 seconds. The nearest approach to this, in anything like round numbers and a decent fraction, is 365¼. To get the proper number of days into the year before the time of Julius Cæsar was a decided failure. About his time the confusion was really inextricable. In 46 B.C. Cæsar brought over from Alexandria Sosigenes, an astronomer at that time greatly distinguished, and he figured out the Julian calendar. To begin properly, it was found necessary to assign

to the previous year 455 days, which circumstance won for it the name of "the year of confusion." The Julian rule assigned to the ordinary year 365 days, and made every fourth year a leap-year, with 366 days. This was an over-correction, as the year is less than 365¼ days by 11 minutes and 14 seconds, which in 900 years would amount to an error of 7 days.

In 1414 it first began to be mooted that the equinox was creeping away from March 21st. In the sixteenth century the equinoxes had gained ten days, and occurred on the 11th instead of the 21st of March. This was confusing the time of celebrating Easter, which the Council of Nice, in 325, decreed should be the Sunday after the full-moon following the vernal equinox. And the equinox in 325 was on the 21st of March. The Church could not brook in silence this confusion of her feasts. In 1582 Pope Gregory XIII. resolved to look into the matter. He appointed Christopher Clavius, a German, Peter Chacon, a Spaniard, and Ignatius Danti, an Italian, to regulate the calendar.

John Herschel, the great astronomer, speaks with admiration of the neatness, accuracy, and wisdom of the Gregorian calendar. Pope Gregory directed that the 5th of October, 1582, should be

called the 15th of October, and thus threw away the ten days that had crept into the year.

The Gregorian rule is as follows: The years are counted from the Birth of Christ. Every year whose number is not divisible by 4 without a remainder consists of 365 days; every year which is divisible by 4, but not by 100, consists of 366 days; every year divisible by 100, but not by 400, consists again of 365 days; and every year divisible by 400, again of 366 days. The actual value of the solar year, reduced to a decimal fraction, is 365.24224; and of the Gregorian, 365.2425; so that the error of the Gregorian rule on ten thousand of the present tropical years is 2.6 days. This is an error of less than a day in three thousand years. This is indeed sufficiently accurate for all civil reckoning. Thus did the Church confer on civilized man one of the greatest and most universal blessings of practical science.

CHAPTER VIII.

Geography.

EOGRAPHY is one of the oldest as it is one of the best developed of the sciences. It has cost immense labor to bring it to its present advanced stage of excellence. No honest geographer will dispute the grand achievements of Catholics in this field of science.

The ancients, for the most part, considered the earth a vast circular plain completely circumscribed by ocean.

Job, besides his extraordinarily correct astronomical views, gives interesting geographical details concerning parts of Asia and Africa. The ancient Phœnicians, Chinese, Egyptians, and Carthaginians had more or less extensive knowledge of neighboring territories.

The expeditions of Alexander the Great added materially to the geographical acquisitions of his time. Eratosthenes, a native of Cyrene and born in the year 276 B.C., was the first real geogra-

pher, in a scientific sense, being the first to employ latitude and longitude. After his time geographers grew in number with great rapidity. Strabo, a native of Asia Minor, born about 54 B.C., is highly praised as a geographer. Pliny has left us a voluminous but indifferent treatise on this subject. Claudius Ptolemy's great work was the standard geography for centuries.

The great Catholic geographers began to loom up early in the sixth century. Cosmas Indicopleustes of Alexandria, towards the middle of the sixth century, wrote a geography which became almost the rival of Ptolemy's for popular favor. Carpino, Rubruquis, and Ascelin, Catholic missionaries, were greatly renowned for their travels and explorations, and were the worthy forerunners of Márco Polo, the celebrated Venetian traveler. He explored almost the whole of Asia.

The Catholic Church was continually sending her missionaries into Asia and Africa for the purpose of conversion. These devoted sons of Holy Church gathered a mighty treasure of valuable information concerning the lands through which they journeyed.

The Portuguese voyagers pushed the limits of geographical knowledge quite considerably, es-

pecially on the African coasts. Then the great achievements of Columbus and his lieutenants in the New World break upon the view. Vasco da Gama, finding the maritime passage to India; Magellan, Vespucci, and others follow in the procession of discovery.

Among the famous works of Catholic authors on geography are a treatise by Albertus Magnus, Cardinal Alliacus' Picture of the World, the Planispherium of Sanuto, the Sea-chart of Paul Toscanelli, Map of the World by La Cosa, Martin Behaim's famous World-Apple, and the Variation-chart of Santa Cruz.

In large works on Trigonometry, under the head of Navigation, are found the different methods of determining a ship's course. Plane, Traverse, Parallel, Middle-Latitude and Mercator's sailing are successively considered. To compute a ship's longitude when she does not sail along a parallel of latitude but upon any oblique rhomb, there are two methods—one called Middle-Latitude sailing and the other Mercator's sailing. The first method is limited in its application, and is slightly inaccurate. The second is unlimited, and absolutely true. This great geographer, Gerard Mercator, was a Catholic, and a student of the University of Louvain.

As it is admitted to be an easy matter to add to inventions, similarly the discovery of a country is of much more merit than its subsequent exploration. We do not deny that there have been great travelers and voyagers, such as Humboldt and Cook, who were not Catholics; but what we claim is our just meed of praise. Catholics have been the great pioneers of discovery. In gathering the materials for the edifice of geography, Catholics have done the great bulk of the work.

CHAPTER IX.

Marco Polo.

WE have inherited almost the whole of the science of geography from Catholic sources. The Church, her great heart throbbing with an incessant love for the souls of men, sent forth, in every age, her apostles to carry the Gospel to the different nations. These illustrious missionaries, in their unfaltering zeal, visited all the countries of the habitable globe, of which they brought back accurate and minute descriptions. The manifold accounts were collated and reduced to a system, and so gave us the science of geography.

Among the names of those whose labors added to our knowledge of the earth's surface, the most illustrious is that of Marco Polo. We have the testimony of Alexander Humboldt that he was the greatest traveler of any age. He was a true and honored son of holy Mother Church. He

sought and obtained the benediction of Gregory X. at the very beginning of his travels.

Marco Polo was born in Venice, of Dalmatian parents, about the year 1250. He began his journeys in company with his father and uncle, successful merchants enjoying an extensive trade in the Orient.

The two merchants, together with young Marco, set out from Venice in 1271, and after many mishaps and by devious courses reached Pekin, bright Cathay's famous capital, in 1275. Here Marco was introduced to the renowned Kublai Khan, the Tartar conqueror of China. The Khan was at once favorably impressed with the bright intelligence and courtly dignity of young Polo. At first Kublai appointed him to an office about his person, and afterwards dispatched him on important commissions to vassal chiefs. Marco Polo executed these diplomacies with admirable prudence, loyalty, and ability. He rose to great favor with the Khan.

His first visit as an envoy was to the court of Anam, in 1277. While here he acquired a great knowledge of the topography of Thibet, Yunnan, Bengal, Mien, and the south of China. He also studied very minutely the manners and customs of

the peoples of these provinces. He showed himself a wonderful adept in acquiring the languages and appreciating the characteristics of the Mongolian races.

He was next sent as envoy to the Song dynasty, with the view of taking an inventory of its archives. Some time later he was appointed governor of Yang-tchow in the province of Kiang-si, in Eastern China, a post he held for three years. He accompanied a Mongol army in an invasion of the kingdom of Pegu, and afterwards accepted an embassy to Tsiampa, the southern part of Cochin-China.

He spent twenty-four years in Asia. In that time he traveled over Central Asia, China, and India, and brought back admirable accounts of a territory containing more than half the people of the entire earth. He traveled over many places never before trodden by Europeans, and visited Japan, whose very existence was not at that time even suspected in Europe.

Among his other exploits he crossed the rainless Gobi; traveled over the great salt desert of Khorassan; visited the capital of Southern China, Kinsai, famous for its boundless parks and gardens, and passed some time at the Persian capital, Teheran.

He set out for home, Venice, in 1291, which he

reached in 1295, sailing through the Chinese Sea and Indian Ocean.

He amassed quite a fortune by legitimate trading during his sojourn in the East. On his return he greatly astonished his neighbors by displaying to them some of the rich and gorgeous costumes worn by the Orientals.

Soon after his return home he took part in a war between Venice and Genoa, the great maritime powers of the period. He was made a prisoner off the coast of Dalmatia, and immured in jail in Genoa for almost five years. During his captivity he narrated his travels from memoranda to his friend and fellow-prisoner, Rustigielo of Pisa. He afterwards revised with great care the manuscript of Rustigielo. The most correct edition of the great and admirable work of Marco Polo is the "Milione," edited by Count Baldelli.

On his return to Venice, after being restored to liberty, he was appointed a member of the Grand Council, and died in 1323.

His work is so full of marvels that it reads like a fairy tale or an Arabian legend. It was at first thought by his countrymen to be the pure creation of a fertile fancy, but his statements were afterwards verified in all the particulars of moment.

As a narrative of travels it is incomparable for minuteness, research, and accuracy. It gave a wonderful impetus to travel and exploration, and created an unbounded desire for discovery. It is said that it was the reading of Marco Polo's "Milione" that first stimulated Columbus, and sent him forth to seek and find a new world. It was certainly the knowledge imparted by the "Milione" that animated the Portuguese to seek Hindustan by way of the Cape of Good Hope.

CHAPTER X.

Christopher Columbus.

HRISTOPHER COLUMBUS, the most illustrious of discoverers, died in poverty at Valladolid, Spain, May 20, 1506. The reliable accounts of his early life are meagre. It is supposed that he was born near Genoa, Italy, some time between 1435 and 1446.

He spent a short portion of his boyhood at the famous university of Pavia, where among other branches of science he studied astronomy and navigation. Displaying very decidedly a maritime taste, he was early sent to sea, where he spent his youth and first manhood.

We find him at Lisbon in 1470, gaining a livelihood by the construction of maps and charts. In studying their maps, Columbus concluded that the ancients were acquainted with 225 out of the 360 degrees of the earth's equatorial circumference, their knowledge stretching from Thinæ in Asia

to the Canary Islands. To this he considered the Portuguese to have added 15 degrees more, in discovering the Cape Verde Islands.

Carefully comparing what was thus known of the earth's surface with the globe of Ptolemy, he calculated that 120 degrees in longitude, or a third of the equatorial circumference, still remained unaccounted for. He thought that new land could be discovered by sailing westwardly. Many things combined to confirm him in this opinion. Numerous evidences of a strange land floating from the west had been reported by mariners. Trees of an unknown species, tropical vegetables, and bodies of a strange race of men, coming in on currents from the open ocean, indicated land towards the west.

From reading the narratives of Marco Polo, Columbus conceived the notion that Asia extended easterly into the great dark western sea. And notwithstanding his several voyages to the New World, he died in the belief that the land he discovered was a portion of Asia.

It was probably in the year 1474 that Columbus finally convinced himself that land lay to the west, and thoroughly made up his mind to seek it. Two personages, very much renowned at this period for

their scientific learning, greatly influenced this decision of Columbus. These were Cardinal Alliacus (Pierre d'Ailly) and the great Florentine astronomer, Paul Toscanelli. Columbus took with him on his memorable voyage a map by Toscanelli, and a copy of the great cardinal's work, "Imago Mundi" ("Picture of the World").

Columbus started out on his voyage of discovery with a well-designed plan, based on the best scientific knowledge of his day. He did not point his prow to the western horizon and let the waves bear him whithersoever they listed. Nor was he driven on the shores of the New World by accidental storms, as Naddod and Gardar to Iceland, and Gunlijörn to Greenland. He set forth as one seeking a destined goal.

In 1484 Columbus first began to apply for aid to carry out his project. He appealed to Genoa, Venice, and Portugal. They looked upon his scheme as the wildest dream of a visionary. The Spanish rulers, whose patronage he also sought, after holding him in suspense for seven weary years, finally appointed a grand council to examine his designs. This august body deemed them entirely impracticable. No reverses, however, could break his indomitable spirit. An invincible faith ani-

mated his noble soul. A holy motive possessed him. He thought that God had chosen him to plant the cross and save souls in some distant land beyond even the *mare tenebrosum* of the Arabian geographers.

Finally, in 1491, Columbus resolved to abandon Spain and commit his fortunes to generous France. Traveling through Andalusia on foot, he stopped for refreshments at the Franciscan monastery of La Rabida, near the seaport of Palos. The guardian, Juan Perez, an eminently learned man, was charmed with the grandeur of the traveler's ideas, and became deeply interested in his wondrous scheme. He succeeded in also gaining over to the views of Columbus Alonso Pinzon, an experienced navigator of Palos. This Father Perez had been formerly the queen's confessor, and so had sufficient influence to obtain from their majesties a new hearing for the great seaman. But Columbus again failed of receiving the desired succor, and, with his face once more towards France, had journeyed some leagues from Granada, where he met their majesties, when a royal messenger overtook and recalled him. The noble soul of woman rose equal to the supreme occasion, and Isabella consented to sacrifice her jewels to the sublime enterprise.

Columbus set sail from Palos on Friday morning, August 3, 1492, with three little vessels, the *Santa Maria*, the *Pinta*, and the *Nina*, and one hundred and twenty men. Columbus commanded the first, Martin A. Pinzon the second, and Vincent Y. Pinzon the third. Columbus and his little band asked with much fervor the benediction of heaven on their hazardous undertaking. Previous to their departure, they confessed to Father Perez and received the Holy Communion. After seventy-one days of ocean they reached the island of Guanahani, San Salvador, one of the Bahama group. Columbus first stepped on shore, and, bearing aloft the sign of redemption and the banner of Castile, knelt down and devoutly kissed the soil of the New World.

Columbus made four voyages to the new hemisphere, adding each time to his discoveries. On his third voyage he touched the mountainous shores of Paria, and from the delta of the Orinoco saw the mainland of South America.

It is sadly to be mentioned that the great achievement of Columbus awakened against him a spirit of great jealousy. He suffered cruel injustice after the death of Isabella. Among the ingredients of his bitter chalice were imprisonment and chains. But the soul of the grand old man rose superior to

injustice and ingratitude, for his was a soul stamped with the heroic characters of God's saints.

Columbus' delineations of the New World are singularly charming. His language is strikingly simple and beautiful, and manifests his intense love of nature. A deep religious sentiment pervades all his descriptions. His ship's journal, his letters to the Chancellor Sanchez, to the Donna Juana, and to Queen Isabella, show that he was a keen observer of nature in the New World. He notices its distribution of heat and terrestrial magnetic variations.

Columbus was the first to determine astronomically that there is a line of no variation of the magnetic needle, and this discovery marked a great epoch in the progress of nautical astronomy. He was the first to describe the equatorial current, or movement of the waters of the ocean between the tropics, and the first to give an account of the Mar de Sargasso, or great sea-weed bank extending from the 19th to the 34th degree north latitude. Columbus was able to find his reckonings by astronomical methods, and was skilled in the use of the astrolabe, though he was unacquainted with the log.

It has been suggested that if Columbus had followed the map given him by Toscanelli, he would

have reached Florida, borne thither by the Gulf Stream, and so the United States of North America would have been peopled by Spanish Catholics instead of English Protestants. He followed, however, the advice of Martin Pinzon, and took a more southern course, reaching the Bahamas. The flight of a flock of parrots to the southwest, towards evening, shaped this advice of Pinzon.

The great discovery of the Genoese seaman, in giving to the world a new hemisphere, not only enlarged our knowledge of the earth, but, by expanding our view of the visible heavens, gave us a broader idea of the universe, and opened up an era of intellectual advancement unequaled in human history.

CHAPTER XI.

Magellan.

FERNANDO MAGELLAN, or, more properly, Magalhæns, the first circumnavigator of the globe, was born in Oporto, Portugal, about the year 1470. He was a fervent Catholic, and in his marvellous voyages was borne onward as much by his zeal for the conversion of souls as by his love of discovery. From early boyhood his life was spent upon the sea, in the fleets of Portugal. He first really distinguished himself, however, in his forty-second year, at the siege of Malacca.

In 1517 he sought the great Ximenes, and tendered his services to Spain. He demonstrated to the famous Cardinal that the then much-valued Spice Islands could be reached by sailing westwardly, and might be thus secured to Spain; there being then a stipulation between Spain and Portugal that all lands discovered 180° west of the Western Islands should be the property of Spain, and all

east of that boundary should belong to Portugal. With this view, the Spanish Government furnished him with a fleet of five small vessels and a crew of two hundred and thirty-six marines.

He set sail from San Lucar, on his memorable voyage, September 20, 1519. Reaching the Patagonian coast, he passed the winter at a place he called Port San Julian. Patagonia, signifying the country of the large-footed, was so named by Magellan from the large footprints found upon the shore.

Leaving San Julian, and going southward, he discovered the dreary archipelago of Tierra del Fuego on the 21st of October, 1520. Tierra del Fuego, the land of fire, was so named by him because of the number of volcanic fires seen around its coast. This desolate group of eleven islands is at the extremity of South America, and is abandoned to the most wretched climate and the most ungainly race of men on the planet. The waters of the Atlantic and Pacific here meet, and struggle together in boisterous conflict, and the inhospitable region is convulsed by those terrific and frequent tempests called the williwaws.

Magellan gave his name to the straits dividing Patagonia from Tierra del Fuego and uniting the

waters of the Atlantic and Pacific. He passed through the straits, 315 miles in length, in thirty-eight days, and was the first European navigator to plough the placid breast of the grand Pacific. Magellan called it the Pacific from the unruffled calmness he experienced while traversing it. After a sail of three months and eighteen days on the great ocean he discovered the Philippine Islands. On one of these, Mactan, Magellan and his little band were attacked in overwhelming numbers by the natives, and he met his death bravely fighting his way to his vessel.

In his great voyage of circumnavigation Magellan endured manifold hardships and displayed traits of heroism of unwonted character. While on the Patagonian shores, four of his captains revolted against him. With prompt address and vigor he quelled the mutiny. Before reaching the Philippines, the heroic little band suffered dreadfully from disease and want of food. Of the five ships that set sail from San Lucar, but one remained, the Victoria, when he reached the isle of Mactan. Of the two hundred and thirty-seven persons leaving Spain, only eighteen again touched its shores. There is a striking parallel between himself and the discoverer of the New World. They encountered

and overcame similar obstacles, and showed the same indomitable perseverance and a like magnanimity of character.

One of the wonders of the heavens are the Magellanic clouds. These two whitish clouds, of unequal size, seemingly detached portions of the Milky Way, give an aspect of singular beauty to the circumpolar southern sky. They are in the immediate neighborhood of the splendid Canopus, the third in the order of brilliancy of all the gems of heaven. In recognition of his great services to geography, and especially of the southern hemisphere, these nebulæ have been popularly named from him, the Magellanic clouds.

CHAPTER XII.

Gama and Vespucci.

SPACE will not here permit more than a skeleton chronology of the lives of these two distinguished Catholic discoverers. Both made very important additions to our knowledge of the earth's surface, and so greatly extended the horizon of geographical science. Vasco da Gama was a fearless and intrepid navigator. As a discoverer he must be placed immediately after the Genoese seaman. The finding of the maritime passage to India is only second in importance to the discovery of the New World.

Emanuel, king of Portugal, intrusted him with four vessels and one hundred and sixty men, and sent him forth to find a southern route to India.

On the 8th of July, 1497, the little fleet left Lisbon, and after a world of hardships reached Beypoor, seven miles south of Calicut, on the 20th of May, 1498. Calicut is one of the chief towns of Malabar, a portion of British India.

In the course of this memorable voyage Da Gama and his flotilla passed the Cape Verde Islands, sailed through the Bay of St. Helena, rounded the Cape of Good Hope (called also most appropriately the Cape of Storms), touched at Natal, the home of the honest Zulu and the liberty-loving Boer, discovered Mozambique, the old slave-market of the world, sighted the island of Acoutado, and finally reached Melinda, on the coast of Zanzibar, a regularly built city with broad streets and neatly built houses. From here they steered across an arm of the Indian Ocean, and directed their course to the shores of Asia. The width of this arm of the third of the great oceans is 750 leagues. Returning home after an absence of twenty-six months, Da Gama reached Portugal with one ship and fifty-five men.

Vasco Da Gama was a man of marvelous resolution. When he had passed the Stormy Cape, and, after an experience of most frightful gales, broke into strange and unknown seas beyond the southern extremity of Africa, the hearts of his sailors died within them. To add to their terror, they saw the weird mirage that in that neighborhood presages a storm, called the ghost of the Cape. They were so overcome with fear, that they refused to go farther.

But Da Gama sternly repressed the mutiny, put the ringleaders in chains, and, undaunted, stretched his course into the open sea. He was a man endowed with a high sense of honor and justice. He was much esteemed and trusted by his country. He was deeply imbued with a religious spirit, loving his religion with a fervid devotion.

The name of Amerigo Vespucci, as just, upright, and honorable a mariner as ever plowed the main, has been very much aspersed and maligned. Alexander Humboldt has, however, fully and fairly vindicated him. The American continent has been named after Amerigo Vespucci through no design on his part, but simply through accident.

His first voyage was to Cape Paria, of which expedition Alonso de Hojeda was commander and Vespucci pilot. His next maritime venture was in the service of Portugal, when he sailed in a like capacity, under Admiral Pinzon, to the coast of Brazil. He wrote interesting accounts of both these visits to the New World, and from the last relation he acquired the reputation of being the discoverer of the mainland of America. In one of his voyages he discovered the Bay of All Saints.

In 1505 he offered his services to Spain. They

were gladly accepted by Ferdinand; and so highly was he esteemed as a navigator, astronomer, and geographer, that he was appointed by that ruler Spanish pilot major. His duties were to prepare descriptions of all coasts, accounts of expeditions, and to examine into the capabilities of pilots.

Vespucci made four trips to the New World, concerning which he wrote elaborate accounts in an interesting style. His writings reached a German geographer, Martin Hylacomylus, of Freiburg, in Breisgau, who was very much captivated by them, and consequently, in a small work, "Cosmographiæ Introductio," gave the name Americi Terra to the new continent. From this small beginning it ultimately transpired that the name of America was universally given to the New World. Vespucci was entirely free from any connivance in the matter.

Vespucci was born at Florence, March 9, 1451, and died at Seville, the 22d of February, 1512. He was a very strict disciplinarian, and an able and intelligent navigator. He was for many years a close friend of Columbus. Vespucci was a scholar, and familiar with the ancient and modern classics, as is clearly evidenced in his elegant descriptions of the Brazilian coast. His delineations

of the tropical luxuriance of the New World's vegetation, and of the richness and variety of its organisms, possess a peculiar charm.

Humboldt satisfactorily proves that Vespucci was altogether guiltless of any endeavor to fraudulently impose his name on the New World. In his exordium to the proof of the integrity of Vespucci's character in this matter, Humboldt writes as follows: "Where the designation of a large continent, generally adopted as such, and consecrated by the usage of many ages, presents itself to us as a monument of human injustice, it is natural that we should at first sight attribute the cause to the person who would appear most interested in the matter. A careful study of the documentary evidence has, however, shown that this supposition in the present instance is devoid of foundation, and that the name of America has originated in a distant region (as, for instance, in France and Germany), owing to many concurrent circumstances which appear to remove all suspicion from Vespucci. Here historical criticism stops, for the field of unknown causes and possible moral contingencies does not come within the domain of positive history. We here find a man who, during a long life, enjoyed the esteem of his contemporaries,

raised by his attainments in nautical astronomy to an honorable employment. The concurrence of many fortuitous circumstances gave him a celebrity which has weighed upon his memory and helped to throw discredit on his character. Such a position is indeed rare in the history of human misfortunes, and affords an instance of a moral stain deepened by the glory of an illustrious name. It seems most desirable to examine, amid this mixture of success and adversity, what is owing to the navigator himself, to the accidental errors arising from a hasty supervision of his writings, or to the indiscretion of dangerous friends."

CHAPTER XIII.

Other Catholic Discoverers.

ASCO NUÑEZ DE BALBOA, a Spanish Catholic, although not giving its name to the Pacific, is credited with catching the first sight of the grand ocean, on the 25th of September, 1513, from the heights of the Sierra de Quarequa, at the Isthmus of Panama. St. Domingo was the first part of the New World visited by Balboa. Not meeting with success in his undertakings here, he resolved to join an expedition preparing to sail for Darien, the Castilla de Oro (the Golden Castile) of the Spaniards. He was forced to escape in a cask as a stowaway, owing to the importunity of creditors. Fortune soon placed him at the head of the Darien colony. From here he started, with a company of two hundred and ninety men in a brigantine and nine large canoes, to find the great western ocean spoken of by the Indians. At Coyba he left the brigantine and canoes, and set out on foot across the moun-

tains. Balboa, in advance of his people, climbing to the top of a mighty peak, caught the first glimpse of the expanding waters. The sublime view filled his soul with ecstasy, and, casting himself on his knees, he fervently thanked God, and devoutly erected a cross upon the spot.

His grand discovery created fresh enthusiasm in Spain, and added a new stimulus to the spirit of adventure.

During his absence, he was superseded in the command of the Darien colony by Pedrarias Davila, a narrow-minded and cruel tyrant. Jealous of the achievements of Balboa, Davila had him seized on the pretense of treason, and executed, without the shadow of justice, in the year 1517.

Francisco Pizarro was with Balboa when he discovered the Pacific. Pizarro afterwards conquered and explored Peru, the country of the Incas and the best organized State of South America. The youngest brother of the great conquistador, Gonzalo, with three hundred and fifty Spaniards and four thousand Indians, passed into the Territory of Quito, on an exploring expedition. From Quito they traveled eastward in quest of a land reputed rich in spices. They forced a passage over the Andes into the "Land of

Cinnamon." Penetrating thence through a portion of the greatest forest on the globe, they reached the Napo, a tributary of the Amazon. The greater number of the explorers were now reduced by starvation and vicissitudes of climate to such a condition of wretchedness that they were unable to proceed further. Pizarro, choosing one of his officers, Orellana, and a few of the most intrepid, sent them forward in search of assistance. This little party, after a few days of wandering, reached, near its head-waters, the Amazon, the most voluminous river of the earth and draining a third of South America. Orellana, unable to obtain supplies even to return to Pizarro, constructed a rude boat and floated down the Amazon to its mouth.

Pizarro and his famished comrades, after vainly awaiting Orellana's return, started back to Quito, which eighty Spaniards and half the Indians survived to reach in a most woe-begone condition, looking more like miserable spectres than human beings. In the story of American exploration, this exploit stands alone for danger, difficulty, and heroic fortitude.

Although Orellana was the first to navigate the Amazon, Father Acuña first described it, and Vin-

cent Yañez Pinzon first saw it. This Pinzon, one of the lieutenants of Columbus, also discovered Cape St. Augustine, Yucatan, and the mouth of the Orinoco.

Hernan Cortes, the brilliant soldier of fortune, explored Mexico, and, at his own expense, fitted out an expedition that discovered California. Lower or Old California had been previously discovered by Ximenes, of Spain; it was first settled, however, by the Jesuit missionaries in 1683.

Space prohibits the narration of the exploits of all the Spanish cavaliers that distinguished themselves by discoveries in the New World. Alonzo de Hojeda, Juan de La Cosa, Pedro Alonzo Nino, Christoval Guerra, Diego de Lepe, Rodrigo de Bastides, Juan Ponce de Leon, conqueror of Porto Rico and discoverer of Florida, can merely be mentioned, while many others must be passed over without even this courtesy.

It was not the mere love of gold that attracted these men to the New World. The spirit of knight-errantry and the hope to Christianize the pagan stirred the breasts of the bold conquistadores.

"It is a curious fact," says Washington Irving, "well worthy of notice, that the spirit of chivalry

entered largely into the early expeditions of the Spanish discoverers, giving them a character wholly distinct from similar enterprises undertaken by other nations."

Marquette and Joliet explored the Mississippi in 1673, traveling in their birch canoes over twenty-five hundred miles.

Fernando De Soto, born in Estremadura, Spain, was a famous explorer. In 1528 he explored the coasts of Guatemala and Yucatan for seven hundred miles. He was with Pizarro in the conquest of Peru. Hearing much concerning Florida, and obtaining permission from the Emperor Charles V. to undertake its conquest, De Soto fitted out at his own expense an expedition with this object. He traveled through the countries of the Appalachians and Chickasaws. These Indians were hostile, and in passing through their territory he braved great dangers and endured many hardships. De Soto was the discoverer of the Mississippi, which, with his little army of followers, he crossed, using barges as transports. He died from an attack of fever, on the banks of the great river, and his body was sunk at midnight in the middle of the stream, a little south of the present site of Helena, Arkansas.

La Salle, Hennepin, and Membré made numer-

ous explorations, and, in 1682, descended the Mississippi to the Gulf of Mexico.

The saintly Father De Smet and other missionaries of the Society of Jesus were the indefatigable explorers of the western Territories of the United States.

CHAPTER XIV.

Mechanics.

THE science of mechanics treats of the laws of equilibrium and motion, and embraces statics, dynamics, hydrostatics, hydrodynamics, and pneumatics. Statics investigates the action of forces in producing equilibrium of solid bodies; dynamics the effects of forces in causing motion in solids; hydrostatics treats of the conditions of rest in fluids; hydrodynamics considers the effects of forces on fluids when motion is produced; and pneumatics treats of the equilibrium and motion of gaseous bodies.

The ancients had a very limited knowledge of mechanics. Archimedes, the greatest among them in this respect, was acquainted with the principle of the lever and, probably, with that of the inclined plane. He has left an explanation of some of the properties of the center of gravity and of the chief doctrines of hydrostatics. Still, his

knowledge of the science of mechanics was circumscribed by very narrow bounds.

We are indebted almost entirely to Galileo and his school for our knowledge of the principles of elementary mechanics. These principles were afterwards developed and applied in practice by other great philosophers, many of whom were non-Catholics, and, though they deserve great credit for this development and application, still their work is of far less importance than the work of those who discovered the fundamental principles.

The three laws of motion are justly regarded as the basis of modern mechanical science. The first law of motion is, that "a body, when not acted on by any external forces, if at rest, will remain so, or, if in motion, will continue to move in a straight line and with a uniform velocity."

It is not known with certainty who the first person was that announced this law in a general form, though the announcement is commonly attributed to Descartes. Galileo, in his Dialogues on Mechanics (1638), states the law correctly. Borelli of Castelnuovo, Galileo's pupil and the great mathematician of the convent of St. Pantaleon, in his treatise on the Force of Percussion (1667), also announces it correctly.

The problem of the law of falling bodies, that the spaces must be as the squares of the times, was first solved by Galileo. He also discovered the second law of motion: "All motion or change of motion in a body is proportional to the force impressed and in the direction of that force."

The principle of virtual velocities, what is gained in force is lost in time, or, the weight raised moves as much slower than the power as it is larger than the power, was stated with much clearness by Galileo, in his Treatise on Mechanical Science, in 1592. Galileo discovered the true proportion which the accelerating force of a body falling down an inclined plane bears to the accelerating force of the same body falling freely. This discovery led him to that of the third law of motion: "Action and reaction are equal and in opposite directions." Torricelli, in a treatise published in 1644, credited his great master with the discovery of this law. The mechanical doctrines of Galileo were taken up and thoroughly verified by his school, which consisted of his pupils and personal friends.

Castelli, "the creator of a new branch of hydraulics," was a pupil and zealous defender of the opinions of Galileo. Another of his pupils was

Evangelista Torricelli, the famous discoverer of the barometer. The Florentine mathematician, Vincenzo Viviani, was the last of Galileo's pupils. He lovingly nursed his old blind master during the last three years of his life.

Borelli, while professor at Pisa, illustrated many of the doctrines of Galileo. Gassendi and Mersenne, his friends, also greatly assisted in their verification. Gassendi, especially, was very happy in his illustrations of the truth of the second law of motion.

Galileo rediscovered the laws of the equilibrium of fluids. He explained the properties of fluids, in his Discourse on Floating Bodies (1611). Pascal, in his Treatise on the Equilibrium of Fluids (1653), shows that a fluid contained in a vessel presses equally in all directions. Galileo discovered that the air has weight. Descartes is thought to have had a share in this discovery. Pascal demonstrated practically, in 1647, that a column of air has weight. He made his great experiment on a church steeple in Paris. Castelli was the first to perceive that the velocity of the flow of a liquid from an orifice in a vessel of water depends on the depth of the orifice below the surface of the fluid. Torricelli discovered that this

velocity is that acquired by a body falling freely through the same space, and is in proportion to the square root of the depth.

Mersenne (1646) was the first to propose the problem of the center of oscillation. Among other Catholic philosophers who gave important aid toward the grand and symmetrical structure of modern mechanics, Piccolomini, Benedetti, Grimaldi, Mariotte, and Cauchy are particularly worthy of mention.

CHAPTER XV.

Mathematics.

HE science of mathematics treats of the properties of magnitude and number. This science is usually divided into two branches, pure and applied mathematics. Applied mathematics has a very wide range, and is interwoven with many of the physical sciences. This chapter will be confined to pure mathematics, which deals with the laws and relations of number and magnitude in the abstract. Under the head of pure mathematics are classed arithmetic, geometry, algebra, analytical geometry, and calculus.

The origin of arithmetic, signifying in Greek to count, is lost in the dimmest twilight of science. It came from Arabia into Europe early in the thirteenth century. The monk Planudes wrote a book on arithmetic in the fourteenth century, and thenceforth it began to flourish. It was greatly assisted in its growth by the contributions of the learned Gerbert.

Algebra branched out from arithmetic, and treats

of the doctrine of equations. The first European work on algebra was written by the Venetian friar, Luca Borgo, in 1494. Ludovico Ferrari solved biquadratic equations. But it was François Viète, of Fontenay-le-Comte, the greatest French mathematician of the sixteenth century and a most zealous Catholic, that gave us algebra as we have it now. He was the creator of modern algebra. He also first applied algebra to geometry, and approximately solved the quadrature of the circle. Viète was certainly one of the greatest abstract mathematicians that ever lived, and must be named immediately after Descartes.

Geometry, meaning in Greek land-measurement, is a very old science, and is mentioned by the father of history. The Greeks greatly excelled in its cultivation. The first great modern advancement in it was made by Descartes, when, imitating Viète in the use of symbols, he invented Analytical Geometry in 1637. Probably the greatest name in the pure mathematics is that of René Descartes, "whose genius," says Humboldt, "was one of the most powerful manifested in any age." He achieved great and lasting results in mathematics. His true greatness as a mathematician enhanced very much his philosophical views, and gave its chief weight

to his physical theory of the universe. His rule for the solution of the higher algebraic equations is still famous, and is as follows: "An equation cannot have a greater number of positive roots than there are variations of sign in the successive terms from plus to minus, or from minus to plus, nor can it have a greater number of negative roots than there are permanences or successive repetitions of the same sign in the successive terms." He gave a new solution of the equations of the fourth degree, first introduced exponents into equations, and was first to show how to draw tangents at every point of a geometrical curve.

The founder of the French Polytechnic School, Gaspard Monge, was a great geometer, and his contributions to mathematics are numerous and valuable. He invented, in 1795, the Descriptive Geometry, or analytical geometry of three dimensions, which is a general application of the principle of projections. Monge was the first to apply the infinitesimal calculus to the general theory of surfaces. Napoleon bestowed great honors upon him for his services to physics and mathematics.

Michel Chasles, a pious Catholic and one of the very greatest geometers, wrote his immortal work, "Géométrie Supérieure," in 1852.

The infinitesimal calculus now in use was invented by the great Leibnitz, who, though not formally a Catholic, was really one in sentiment.

Cauchy was a great analyst and the chief developer of the calculus of imaginaries. He is celebrated in algebra for his brief and lucid demonstrations.

The brilliant Pascal aided Leibnitz in the invention of the differential calculus.

With Descartes, Viète, Cauchy, Monge, Chasles, Biot, Nollet, and Pascal, Catholics certainly have no dearth of eminent names in mathematics. And to this bright galaxy may be added the other great Catholic names in mathematics, Regiomontanus, Copernicus, Galileo, Reisch, Cavalieri, Mersenne, Laloubère, Maurer, Inniger, Adrianus, Puisieux, and Lesueur. The Jesuits have a long array of celebrated names in mathematics, and among them are those of Moigno, Riccati, Boscovich, and Maco.

CHAPTER XVI.

Acoustics.

ACOUSTICS is the science of sound. Sound is a sensation produced by the undulations, or waves, of some elastic medium falling upon the organs of hearing. It is always the result of rapid oscillations, or vibrations, imparted to the particles of elastic bodies, when their equilibrium has been disturbed either by a shock or by friction. The ordinary medium through which sound is conveyed to the organ of hearing is the air. Sound-waves may also be propagated through liquids and through solids, provided they possess the property of elasticity. Indeed, water is a better conductor of sound than air, in the ratio of four to one; and elastic solids are still better than water. Sound is transmitted through glass with eighteen times the rapidity with which it travels through air.

In order to produce the sensation of sound, the undulations must have a great rapidity. The

lowest number of oscillations in a second, sufficient to produce sound, is 16½, and it is doubtful if the human ear is capable of recognizing a sound when the number of vibrations in a second pass 16,000. This is thought to be the limit, or the highest tone that the ear can discriminate.

When an elastic body receives a single blow, the sound occasioned is called a report. When the blow is repeated at regular intervals, producing equal waves that strike the ear with such rapidity that the intervals cannot be distinguished, it is called a tone. The ear distinguishes three characteristics in sound: the tone, or pitch, which is governed by the rapidity of the vibrations—the greater the velocity of the waves, the more acute will be the sound; the intensity, which decides whether a sound is loud or soft, depends on the amplitude or depth of the vibrations; the quality, or timbre, by which the notes of different instruments, as the violin, harp, or flute, are distinguished from one another.

An elastic medium is requisite for the transmission of sound. No sound can be produced in a vacuum. The velocity of sound in air has been ascertained to be 1090 feet a second, when the temperature is 32 degrees Fahrenheit. It increases

nearly a foot a second for every degree above 32 degrees. Ordinarily, the human voice is heard at the distance of 700 feet, but often it is heard much farther. There is an instance on record of its being heard a distance of 10 miles. A volcanic eruption has been heard a distance of 300 miles.

All sounds, however, in the same medium travel with the same velocity. A whisper is heard at the same moment with the loudest tone. When we listen to distant music, all the tones reach us with the same velocity; otherwise there would be confusion instead of harmony.

The intensity of sound, however, diminishes with distance, the law being that the intensity of the waves will be inversely as the square of the distance from the center or source of sound.

Sounds falling on different surfaces are reflected, the angle of incidence being always equal to the angle of reflection. Sound-waves are also refracted when passing from a rare to a more dense medium, and the contrary.

The relation between a vibrating string and musical notes is governed by the three following simple laws: 1. The number of vibrations is inversely as the length of the string. 2. The number of vibrations is as the square root of its tension, or

stretching weight. 3. The number of vibrations of strings of different thickness is inversely as their diameters.

Although the theoretic principles of acoustics may be said to be well known and well understood, yet in practical life this science has produced no satisfactory result. Indeed, in recent years very little has been accomplished in either the mathematical or practical part of the science. Among the physical sciences, acoustics may well be said to be bringing up the rear.

The very earliest philosophers of antiquity recognized that sound was produced by some motion of the sounding body, and conveyed by some motion of the air to the ear. Pythagoras and Aristotle, particularly, expounded this opinion. It must be conceded, however, that their conception of the true nature of sound was very vague indeed, and their manner of expressing it extremely wavering.

Galileo laid the foundation of mathematical acoustics. Father Mersenne may be said to be the first great author on sound vibrations, in his "Liber Harmonicorum," Paris, 1636. He made a great number of experiments with vibrating strings. He demonstrated that the differences and concords of acute and grave sounds depend on the rapidity

of vibrations, and their ratio. It was Mersenne that showed the effect of thickness and tension. A string must be four times as thick as another to give the octave below; and the tension must be four times as great in order to produce the octave above. It was Mersenne that determined experimentally the number of vibrations of a string required to produce the different notes.

Gassendi was one of the first to measure the velocity of sound. This he did by means of fire-arms. He found the velocity to be 1473 Paris feet in a second.

Cassini and Picard, among others, afterwards found it to be 1172 Paris feet in a second. Gassendi was the first to perceive that a loud and a gentle sound travel with the same velocity. It was Mersenne that first recognized the existence of secondary notes, or that, when a string vibrates, one that is in unison with it will vibrate without being touched.

M. Cauchy calculated the transverse, longitudinal, and rotary vibrations of elastic rods. So that, toward the development of acoustics, Catholic physicists have certainly done their share.

CHAPTER XVII.

Optics.

PTICS is the science which treats of the nature and phenomena of light. Optics may be said to be almost entirely of modern growth. The ancients knew the law of reflection, and were acquainted with the phenomenon of refraction; but the belief that the rays of light proceeded from the eye to the object, instead of the contrary, was nearly universal among them.

There are, principally, two theories purporting to account for the phenomena of light. One is the emission or corpuscular theory, which supposes the source of light to throw off luminous particles so minute as to be imponderable, and that these, impinging on the organs of vision, produce light. The other is the undulatory theory. This supposes an imponderable ether extending out into interstellar space and filling the interstices of all bodies, however hard or seemingly impenetrable. Vibrations in the particles of this ether, transverse or, indeed,

perpendicular to the direction of the ray, are the origin of light.

It may be said that this theory is now universally accepted by physicists. It alone gives a satisfactory solution of all the phenomena of light. It explains reflection and refraction equally as well as the emission theory, and gives the only consistent explanation of the interference of light, polarization, double refraction, dispersion, and diffraction.

When light is reflected from a surface, it obeys a very simple law. The angle of incidence is equal to the angle of reflection. The angle of incidence is that made by the incident ray with the perpendicular, and the angle of reflection is the one made by the reflected ray with the same perpendicular.

When a ray of light passes from one medium into another, it is bent from its course at the surface of division, and is said to be refracted. A ray of light always travels in a straight line in the same medium, if this be homogeneous. The whole ray is never transmitted, as a portion is reflected, and a portion scattered in all directions. When a ray of light passes obliquely from a rare to a more dense medium, it is bent toward the perpendicular; and from a dense to a rarer medium, from

the perpendicular. "It is a universal law of refraction at plane surfaces, that the paths of the ray before and after transmission always lie in the same plane with the perpendicular to the refracting surface drawn to the point of transmission, and on opposite sides of that perpendicular; and in that plane the sines of the angle of incidence and of refraction have in all cases the same ratio for any two given media." The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for the same medium, and is called the index of refraction. But the ratio varies for different substances.

The dispersion of light is its decomposition or separation into its primary colors. White light is composite, being constituted of seven simple colors. A lens or prism has the power of producing dispersion. There is nothing really definite concerning the exact number of primary colors. Some contend for many more, and some for fewer than seven. Red, orange, yellow, green, blue, indigo, and violet are named as the primary colors. They are unequally refrangible; that is, after decomposition they are found at different distances from the original direction of the beam. Red has the least, and violet the greatest, refrangibility.

Two waves of light may interfere, and thus increase or destroy each other's effects. When two waves emanating from the same source act on a particle of ether, it vibrates with an intensity corresponding to the combined forces of the waves; the same thing occurs, providing the waves are of equal length, or differ by a given number of entire waves, even when they emanate from different sources. But if two waves, acting on a particle of ether, differ by any fractional number of undulations, they oppose each other's action, and so actually produce partial or total darkness.

The amplitude of the vibrations of the ethereal particles determines the intensity of light, but its color depends on the rapidity of vibration. The length of a wave of light is very small indeed. A wave of red light is the 256 ten-millionth of an inch long, and of violet light 174 ten-millionths of an inch. The velocity of light itself is about 185,000 miles a second. The number of vibrations of violet light in a second is 710 millions of millions. This latter calculation admits of a very simple geometric demonstration.

Diffraction is the divergence of the rays of light in passing the edge of an opaque body, causing the appearance of parallel fringes of prismatic colors.

The emission theory utterly fails to account for this property of light. The undulatory theory satisfactorily explains it, on the principal of interference.

The double refraction of light is caused by a property of many transparent crystals, such as Iceland-spar and carbonate of lime, owing to their peculiar structure. A beam of light transmitted through these crystals is split into two portions —one called the ordinary, and the other the extraordinary ray. An object seen through such crystals presents two images to the eye.

If a ray of light is reflected or transmitted at certain angles of incidence, it is rendered incapable of being again reflected or transmitted, excepting at certain angles of incidence, and is said to be polarized. Light can be polarized by either reflection or refraction. If we take a plate of unsilvered glass and hold it obliquely at an angle of about 56°, and allow a beam of light to be reflected from it onto another similar glass plate, almost the entire beam will be again reflected from the second plate when held in a position parallel to the first. If the second plate be turned so that, instead of being parallel to the first, it becomes perpendicular to it, none of the light will be reflected from the second plate, the light being completely extin-

guished. This peculiar property imparted to the beam of light by the first reflection, rendering it less capable of being reflected by the second plate, is called polarization by reflection.

Light passed through certain crystals, and particularly the mineral crystal tourmaline, is no longer affected like common light, and possesses this property of polarization. The internal structure of this crystal is such that a ray of light which has passed through a thin plate of it cannot pass through a second, if it is placed in a position at right angles with the first. This is polarization by refraction. Light is polarized in a number of ways, as by passing it through a bundle of plates of thin glass or mica, by reflection from polished non-metallic surfaces and at particular angles for each. This is plane polarization. Many crystals have the power of imparting to light the properties of circular and elliptical polarization. Quartz, a uniaxial crystal, gives circularly, and nitre, a binaxial one, elliptically polarized figures.

It will scarcely be disputed that the greatest name in optics—a good Catholic one—is that of Augustin Jean Fresnel. Fresnel demonstrated the truth of the undulatory theory of light, by showing, with rare analytical powers, that it, and it

alone, could account for the principle of interference. In his experiment, by which he established the truth of this theory, Fresnel employed two mirrors placed together at a very obtuse angle, and reflected from their surfaces upon a screen light from the focus of a lens, in such a way that, on reaching the screen, some of the undulations of two converging rays should correspond, and intensify one another; while others should be separated by half a wave-length and destroy one another. In fact, Fresnel explained, in the clearest manner and by striking experiments, all the properties of light, on the principle of the undulatory theory. His practical application of the undulatory theory of the mode of the propagation of light to the improvement of the light-house system was of incalculable value, and has quite abolished the old method of illuminating light-houses.

Another great Catholic name in optics is that of Biot. He discovered the principal laws of rotatory polarization. They are the following: "1. With the same substance the rotation of the plane of polarization is in proportion to the thickness of the substance traversed. 2. When two plates are placed together, the effect is nearly the same as that of a single plate whose thickness is equal to the sum or

difference of the two plates, according as they rotate the ray in the same or opposite directions. 3. The degrees of rotation of the plane of polarization vary with the different rays of the spectrum, and increase with their refrangibility."

In 1808, Malus, a Catholic physicist, discovered the phenomenon of polarization, while looking through a doubly-refracting prism at the light of the setting sun, reflected from the surface of a glazed door standing at an angle of 56° 45′, which is the angle at which glass polarizes light by reflection. Malus also discovered, in 1811, the depolarization of white light, or that a pencil of polarized light recovers its original power of being reflected after being transmitted through certain crystals. Malus also detected the law of double refraction, and was the inventor of a polariscope.

In 1849 M. Fizeau measured the velocity of light by means of a toothed wheel, and found it to travel at the rate of 185,000 miles a second. The wheel was placed at Suresnes, and the mirror to reflect the teeth at Montmartre—a distance apart of 28,516 feet.

The property of light called diffraction was first observed and partially explained by Grimaldi, an Italian Catholic physicist, in 1665.

Descartes, the founder of the modern mechanical philosophy, must be considered as the genuine author of the explanation of the rainbow. He showed that the sunbeams, meeting the spherical drops of water, undergo two refractions and a reflection, and reach the eye at an angle of forty-one degrees with their original direction.

Among other Catholic physicists whose labors helped the progress of the science of optics, Monge, Cauchy, Maraldi, and Ampère hold distinguished places.

CHAPTER XVIII.

Thermotics.

THERMOTICS is the science treating of the phenomena and properties of heat. Two rival hypotheses undertake to account for the evolution of heat.

The hypothesis of emission claims that minute imponderable particles of matter proceed from the source of heat in all directions, and thus communicate this property to other bodies.

The undulatory hypothesis supposes heat to be the result of a vibratory motion of an imponderable ether permeating all space, and these ethereal vibrations to be similar to the light producing vibrations, if not absolutely identical with them.

Like light, heat has been found capable of reflection, refraction, and polarization, and these phenomena can be with thorough satisfaction explained only by the undulatory hypothesis. The causes of heat are the sun, friction, percussion, chemical ac-

tion, electricity, vital action, and terrestrial radiation.

By the conduction of heat is meant its passage from particle to particle of a continuous body, or from the particles of one body to those of another in contact with it. Solids are the only bodies that may be really said to be capable of conducting heat. Metals are ordinarily the best conductors, and their conductivity varies widely. Gold is the best conductor, while silver and copper come immediately after. The conductivity of liquids is very poor indeed. Water or other liquid is never heated by conduction. Heat applied from beneath to a vessel containing water warms the film of particles in contact with the vessel. These becoming warm expand and ascend, the cooler particles descending to replace them. The lighter particles ascending and the cooler ones descending form rapid currents when the water is boiling. This whole process is called convection. The conductivity of gases is even worse than that of liquids. Gases are also heated by convection. The atmosphere is warmed in this way. The layer of air in immediate contact with the earth is heated, and, being rendered lighter, ascends, while the cooler particles descend. These ascending and descend-

ing currents are plainly visible on a summer day to a person approaching a hillside.

By radiation is meant the diffusion of warmth in all directions from the surface of a heated body to points not in contact with it. Radiant heat is given off in right lines, and passes through air and other gases without heating them. When radiant heat falls upon liquid or solid surfaces, it is either reflected similarly to light, absorbed, and so retained; or transmitted, and so partially passed through the body.

A concave mirror will bring the rays of heat to a focus, and heat is reflected according to the same laws as light. Polished surfaces reflect heat, and the more highly these are polished, the more readily they reflect. Burnished gold is the best reflector, and reflects 76 per cent of the rays incident at an angle of 60°. Polished silver and brass follow next, and reflect 62 per cent.

Bodies having black and dull surfaces absorb heat very rapidly, and part with their own heat by radiation with equal facility. Surfaces covered with lampblack have the greatest power of absorption, and consequently excel in radiation. Polished surfaces that reflect well absorb poorly and radiate slowly. Metallic vessels with highly pol-

ished surfaces will longest conserve the heat of warm liquids placed in them.

The formation of dew is owing to radiation, the earth parting with its heat during the night, and condensing the vapor in its immediate neighborhood. Grass and plants receive the most dew, because their points radiate very rapidly. These points, parting easily with their heat, grow quickly cold and condense the vapor coming in contact with them.

A lens made of rock-salt will refract the rays of heat passed through it. Heat is governed by the same laws of refraction as light. Rock-salt is used because it transmits more of the rays of heat than any other substance, 96 per cent of the incident heat-rays passing through it. Rock-salt is, then, the most diathermanous of bodies. Glass, on the contrary, transmits very little heat, and is said to be adiathermanous. Simple gases offer scarcely any resistance to the passage of heat; the contrary is true of compound gases. Heat may be doubly refracted, planely and circularly polarized.

One of the most notable, as it is one of the most general, effects of heat, is to cause bodies to expand. The tire of a wagon-wheel is highly heated, and thereby enlarged, that, contracting when cooled, it

may tighten the wood-work of the wheel. Boiling water runs over the rim of its vessel. Air confined in a bladder and heated expands the bladder; and pendulums have to be compensated, to counteract the effects of heat. The property of heat by virtue of which it causes bodies to expand is utilized as a means of measuring temperature. A volume of mercury is chosen because mercury expands nearly uniformly for equal increments of heat. A thermometer is the measurer of temperature. There are various forms of the mercurial thermometer, and, in order to make them comparable, they have two fixed points, the melting-point of ice and the boiling-point of water.

The capacity of any body for heat is called its specific heat. If equal weights of mercury and water are exposed to the same heat, the mercury will reach a given temperature thirty times more rapidly than the water. The capacity of mercury for heat is then said to be thirty times less than that of water. The comparison is always made by weight, and water is taken as the standard. The specific heat of mercury is accordingly one-thirtieth. It has been found that there is a close connection between the specific heat and atomic weight of bodies; so much so that the specific heats are al-

most inversely as the atomic weights. The atomic weights of bodies are the proportionate weights in which they enter into combination.

It is found by experiment that one pound of water at 32° mixed with one pound at 172° will give two pounds at 102°. But if a pound of ice at 32° be mixed with a pound of water at 172°, the mixture will be found to result in two pounds of water at 32°. So that the liquefaction of ice absorbs 140°. These degrees are not sensible to the thermometer; they are concealed, and so are called latent heat. It requires 140° of latent heat to reduce water from the solid to the liquid state. Whenever the liquid is condensed to the solid state, this latent heat is given out in a sensible manner, and may be measured by the thermometer. It is also found by experiment that when water is changed into the gaseous state it absorbs an enormous amount of heat. Indeed, it requires the absorption of almost 1000° of heat to convert water into steam. One thousand is, then, the latent heat of steam. On the condensation of the steam this heat is given out in a sensible form, and may be measured by the thermometer. Different vapors have different degrees of latent heat. Alcohol has 457°, ether 313°, and nitric acid 550°. By the

evaporation of liquids a great degree of cold can be reached. The vaporizing liquids take their heat from the surrounding bodies, greatly reducing their temperature. In this way water may be frozen in a red-hot crucible by the evaporation of anhydrous sulphuric acid.

The great name in thermotics is a Catholic one, that of Jean Baptiste Joseph Fourier. He investigated the mathematical theory of conduction with great ability. His memoir on this subject is the admiration of mathematicians for the wonderful analytical skill it displays. The French Institute, in 1810, proposed as its prize question: "To give the mathematical theory of the laws of the propagation of heat, and to compare this theory with exact observations." Fourier's memoir was, in 1812, adjudged the prize of three thousand francs. Among the statements of Fourier is one to the effect that the planetary spaces are not absolutely cold, but have a proper heat derived from the radiation of the multitudinous stars that people the universe.

Macedonio Melloni, a Catholic physicist of Parma, is famous for his researches in thermotics. He established the analogy of radiant heat to light, by his discovery of heat in lunar light. Our

knowledge concerning the laws of the transmission of heat through diathermanous substances has been derived almost entirely from the experiments of Melloni. He has called rock-salt the glass of heat, because of the readiness with which it allows the rays of heat to pass through it. The researches of Melloni owe their great value principally to the use of a heat-measurer of almost infinite sensitiveness, called the thermo-electric pile, invented by himself and his Catholic countryman, Nobili. This little apparatus consists of about fifty tiny bars of antimony and bismuth, arranged in alternate layers. The most minute difference of temperature generates an electric current in this instrument. Among some of the analogies between heat and light discovered by Melloni, the following are the most remarkable: "1. Unstained glass seems equally transparent to all kinds of light. Such is the case with rock-salt and heat. 2. Light which has passed through a blue glass loses far less per cent when it passes through a second plate of blue glass. Similarly, heat loses, say, 75 per cent in passing through one plate of crown-glass, and only 10 per cent of the remainder in passing through a second. 3. Blue light passes easily through a blue glass, which almost entirely arrests red light. So, dark heat

passes far less easily through glass than bright heat does."

Dulong and Petit have, by their industry, added much to the advancement of thermotics. They discovered that, though fluids expand regularly up to 212°, beyond that point their expansion increases much more rapidly than that of air. They determined the law of the cooling of heated bodies in a vacuum, and found that the rapidity of cooling decreases in geometrical, as the temperature diminishes in arithmetical, proportion. They also established that the specific capacity of bodies increases as their temperature rises. It takes more heat to raise a body from 200° to 205° than from 100° to 105°. Dulong and Petit, in 1819, discovered the law of atomic heat, or the specific heat of atoms, which is of very great importance in chemical researches.

Henri Victor Regnault, a Catholic physicist of Aix-la-Chapelle, made many elaborate researches in thermotics. He has given a table of specific heats of solids, admirable for its accuracy. A discovery of Regnault's is that the specific capacity of a body rapidly increases as it nears its melting-point. The results of his investigations on the specific heat of gases are very important. Regnault always took

the greatest pains to have his experiments as exact as possible. On this account, his views on the relation between temperature and the elasticity of steam are much valued.

Edme Mariotte, the prior of St. Martin-sous-Beaune, was celebrated as a physicist in the first half of the seventeenth century. Everybody who has ever read of the effects of caloric on the expansion of gases will remember his famous law: The temperature remaining the same, the volumes of gases are in the inverse ratio of the pressures which they support.

Sanctorius, an Italian Catholic, made the first thermometer. It was an air-thermometer, depending upon the expansion of a volume of air by heat, and was very accurate, seeing that air expands more uniformly than mercury. It has been replaced by the mercurial thermometer, because it is not capable of measuring any considerable range of temperature.

Among other great Catholic physicists who have added by their industry to the progress of thermotics may be mentioned Biot, Cauchy, Nobili, Pascal, and Ampère.

CHAPTER XIX.

Electricity.

THE oldest form of electricity known to man is magnetism, and its existence was recognized more than a thousand years before the Christian era. Pliny is on record as giving magnetism its name. Pliny found lodestone, an ore of iron having the property of drawing to itself particles of iron, cobalt, and nickel, in great abundance in Magnesia, Lydia, and called it *magnes*. From *magnes* comes magnet and magnetism.

For the first mention of the electric property, we must go back to Thales of Miletus, Asia Minor, one of the Seven Wise Men of Greece. Thales lived some six hundred years before Christ. Electricity comes from *electron*, amber, because it was in rubbing amber the property was first perceived. Amber, rubbed with a silken cloth, will attract light bodies. The word itself, electricity, was coined by Gilbert of Colchester, in 1600 A.D. The science of electricity has not reached its present development

through the genius of any few men however renowned, but is the production of the zealous and united labors of many great philosophers. There is space here to notice only the principal stages of this development.

Early in the seventeenth century a number of philosophers began to experiment in frictional electricity, and so commenced the slow formation of the science. In 1749 Franklin announced the results of his great experiments to the world. Coulomb, by means of the torsion-balance electrometer, which he invented, established the fundamental laws of statical electricity; and, by a number of beautiful experiments, furnished such convincing proofs in favor of the two-fluid theory that it was called after him the Coulombian theory. Coulomb also established the laws of magnetic attraction and repulsion. In the reduction to a science of common, frictional, or statical electricity, Coulomb certainly did more than any other man.

In 1790, when Galvani was professor of anatomy at Bologna, and made his great experiment with frog-legs, electricity, as an experimental science, had almost reached a stand-still. Galvani's discovery of the convulsions of the limbs of a frog when accidentally touched by the conductor of a charged

electric machine was principally of importance in what it led him on to do. His great experiment was when he found that the contact of different metals also caused the movements of the limbs. This was the beginning of galvanism, or voltaism, or dynamic electricity.

From Galvani's experiments dates a new and important era in the world of science. Volta continued in the footsteps of Galvani, and made the most astonishing discoveries. By the power of his genius and his indefatigable industry he invented the voltaic pile, the first galvanic battery. With the galvanic battery began the extraordinary progress of dynamic, or current, electricity. Galvanic batteries rapidly grew in number and strength.

In 1819 Oersted of Copenhagen recognized the property of electro magnetism, or that the electric current developed magnetism in iron.

Ampère soon after discovered the laws of electro-magnetism, the mutual attraction and repulsion of voltaic currents, and announced his great formula for determining the conduct of the magnetized needle under the influence of these currents.

In 1837 Faraday discovered magneto-electricity, or that magnetism is capable of developing electric currents.

A continuous electric stream and the electro-magnet, the essentials of the telegraph, being at hand, that wondrous instrument was born in 1835. Inventors began also to devise magneto-electric machines, or dynamos for furnishing the electric light. These dynamos gradually advanced in perfection, until the incomparable Gramme machine was given to the world. Finally, Gaston Planté invented a storage battery, or apparatus for storing electric energy. The Gramme machine was found to be reversible; not only could it generate electricity, but the electric current could through its agency be transformed into a motive force for turning machinery. Storage-batteries, in conjunction with the Gramme dynamo, have been applied to the running of railroad cars. Commerce has verily harnessed the thunderbolt. The wings of the lightning now bear the world's messages, and its energy may soon carry the world's freight.

CHAPTER XX.

Galvani and Volta.

THE labors of Galvani and Volta furnished a constant stream of electricity. Galvanic or voltaic electricity is also called dynamic electricity, or electricity in motion, to distinguish it from frictional electricity, which is said to be statical, or bound.

Electricity, to be of value in commerce, must flow in a continuous current. The electricity employed in telegraphic communication is the result of chemical action, and is galvanism. When strips of dissimilar metals are held upright and apart in a glass vessel containing acidulated water, and their extremities external to the liquid joined by wire, they produce an electric current. This current will continue as long as the acid acts on the metals, or until the acid is exhausted. A combination of this kind is called a galvanic pair, or battery. There are many varieties of galvanic batteries, depending on the metals and acids employed.

Daniell's consists of copper and zinc, and sulphuric acid; Grove's, of platinum and zinc, and sulphuric and nitric acids; Bunsen's, of carbon and zinc, nitric and sulphuric acids. There are also many modifications of Daniell's extensively in use, as the gravity battery, Meidinger's battery, Siemens-Halske's battery, and so on.

These batteries supply a stream of electricity, which, running along a wire with enormous velocity, induces magnetism, during the flow of the current, in soft iron bars having the wire coiled about them in the form of a helix. These temporary magnets, or electro-magnets, as they are called, draw down a lever which produces a sound. These sounds are of long or short duration, according as the break of the current's flow is of long or short interval, and the sounds are language to the operators.

All the wonderful uses of electricity in modern commerce date from the period between 1786 and 1794, in which Galvani made his great discoveries. The convulsions produced in frog-legs by accidental contact with an electric machine, perceived by his wife and communicated by her to Galvani, led him to other experiments. He found that the simple contact of dissimilar metals produced twitchings

in the legs. This was the real beginning of the electricity of chemical action. The report of Galvani's experiments produced great commotion, and they were repeated with enthusiasm in all parts of Europe.

Alexander Volta became especially interested in them; and having been an ardent student of electricity during thirty years previously, he had acquired great experimental skill in the science as then known. Accordingly he set to work intelligently and with invincible assiduity to push forward the experiments commenced by Galvani. He soon made Galvanism a new science, and actually invented a complete galvanic battery. This first battery is known as the voltaic pile, and is considered the most extraordinary achievement of one man in the history of the human mind. Volta's pile consisted of alternate plates of zinc and copper, with the interposition of layers of cloth saturated with acidulated water. The series proceeded in this wise: copper, zinc, cloth; copper, zinc, cloth; and so on, through thirty or forty alternations. The first copper was connected by wire with the last zinc, to complete the circuit.

The galvanic battery has certainly been much

perfected since the days of Volta, for it is easy to add to invention. We owe, however, in most part, the science of galvanism to these two Catholic scientists, Galvani and Volta.

CHAPTER XXI.

Coulomb and Ampère.

N reducing electricity to a scientific form and establishing its laws, almost the whole work was done by Coulomb and Ampère, both good Catholics. Charles Augustin de Coulomb, a native of Angoulème in France, invented, in the latter part of the last century, the torsion-balance electrometer, and thus furnished a very delicate means of detecting electricity and measuring its quantity. Coulomb's apparatus has played an important part in determining the laws of electric forces.

The outer part of this electrometer consists of a glass cage having a long, slender glass neck. Down through this neck, and reaching to about the middle of the cage, runs a light film of spun glass, having attached to it a light beam of gum-lac, ending in a gilt pith-ball. Almost in connection with this pith-ball is another gilt pith-ball, the terminus

of a brass rod coming down from the top of the cage. This latter ball is called the carrier ball. The upper end of the glass thread terminates in a key furnished with an index moving around a circle graduated into 360°. When an excited body touches the rod in connection with the carrier-ball, this ball becomes electrified, and imparts some of its electricity to the other pith-ball. The two balls are thus similarly electrified, and the carrier-ball, being stationary, repels the other ball. The key at the top is turned until, by twisting the glass film, the two balls are again brought together. The number of degrees through which the key has to be turned to overcome the repulsion is a measure of the torsion, and so is an approximate measure of the quantity of electricity.

With this apparatus Coulomb demonstrated these two laws: "1. The force of attraction and repulsion between two electrified bodies is in the inverse ratio of the squares of their distance. 2. The distance remaining the same, the force of the attraction and repulsion between two electrified bodies is directly as the quantities of electricity with which they are charged."

Coulomb also demonstrated with his electrometer that electricity resides altogether on the surface of

bodies; for, if a solid and a hollow sphere of the same diameter be brought together, one having free electricity, the charge will be equally divided between them. Also when a hollow, insulated globe, having an aperture, was charged with electricity, the interior surface was found by Coulomb to contain no free electricity.

It is well known that an insulated electrified body parts slowly with its electricity. It is dissipated partly through the air and partly through the supports; for no substance is absolutely a non-conductor. Coulomb found that "the rate of loss is simply proportioned to the charge or quantity of electricity, so that at equal intervals of time the charges form a decreasing geometrical series similar to the law of cooling bodies."

Coulomb's is the greatest name in statical electricity, and the two-fluid theory is called after him the Coulombian theory, because of the irrefragable proofs he furnished in its favor. Coulomb proved that the law of attraction and repulsion is the same in magnetism as in electricity. He also introduced into magnetism his two-fluid theory, using austral and boreal as the names of the respective fluids. Coulomb's theory of magnetism is, that a magnet is composed of a vast number of small elements or

particles, each particle having an austral and boreal pole. The austral of one particle neutralizes the boreal of the adjacent particle, and so on, until the ultimate particles are reached, where the fluids, ceasing to be neutralized by any succeeding particles, are free, and form the austral and boreal pole respectively.

André Marie Ampère was as devoted to his religion as he was to science, and that is saying a great deal. He was a native of Lyons, and flourished in the early part of this century. Ampère was the great discoverer of the Amperian or electro-dynamic theory. The early students of magnetism and electricity perceived a strong analogy between them. For instance, bodies similarly electrified repel, and dissimilarly attract, each other. And so the like poles of a magnet repel, and the unlike attract, each other. Accordingly strenuous efforts were made to either prove the identity of magnetism and electricity, or to determine their relationship to one another. The results were entirely unsatisfactory previous to the year 1819. In that year, Professor Oersted of Copenhagen, in one of his experiments, perceived that a current of electricity passing along a wire running parallel to a compass-needle caused the needle to

place itself at right angles to the direction of the wire. This news created much interest in England, France, and Germany, and the electricians of these countries attacked with fresh vigor the question of this relationship between magnetism and electricity.

The one who outstripped all others in his avidity to solve the problem was Ampère. So great was his mathematical sagacity and philosophical acumen, that in a very short time he developed the whole subject, and elevated electro-magnetism to the rank of a new science.

Ampère discovered that parallel wires bearing currents of electricity in the same direction attract, and currents in opposite directions repel, each other. His theory of magnetism is, that a magnetized bar consists in currents of electricity revolving at right angles to the length of the bar around each particle of the metal, the resultant of which would be a great current running around the circumference of the bar.

Ampère considered that the magnetism of the earth consists in electric currents running around it from east to west. According to the theory of Ampère, it will be easily seen how the effect of the earth's magnetism on the needle is neither attractive nor repellent, but directive. Ampère's great

formula for the movement of the magnetized needle under the influence of a parallel wire bearing an electric current is as follows: Let any one suppose himself to be lying in the direction of the positive current, his head representing the copper, and his feet the zinc, and looking at the needle, its north pole will always move toward the right hand.

Ampère was a most beautiful scientific character.

CHAPTER XXII.

Gramme and Planté.

ELECTRICITY has a variety of names. One of them is electro-magnetism. Electro-magnetism is induced in a piece of soft iron when a wire in the form of a helix runs around it carrying a galvanic current. The soft iron becomes, during the passage of the current, an electro-magnet.

Another is magneto-electricity. When a magnet is inserted in a wire coiled as a helix, it induces a temporary electric current in the wire. When the magnet is withdrawn, it induces another temporary current in a direction opposite to the first. This induced current is called magneto-electricity. If the magnet be repeatedly inserted and withdrawn, a series of currents will be produced in the coil.

If an electro-magnet be rapidly revolved on an axis in front of the poles of a large permanent magnet, a series of induced currents will be mani-

fested in the wire of the electro-magnet; for, when the poles of the electro-magnet come just opposite those of the permanent magnet, the electro-magnet will be magnetized, and induce a current in its helix. When the poles are separated by the revolution of the electro-magnet, the electro-magnet discharges its magnetism, and so induces a current in the helix in a direction opposite to the previous current. There are thus in every revolution of the electro-magnet four induced currents, two in one direction, and two in the opposite.

By constructing an apparatus in such a way that an electro-magnet may be rapidly revolved in the vicinity of the poles of a large, fixed, permanent magnet, with the addition to the axis of the electro-magnet of a commutator, or a break-piece composed of alternate ribs of copper and ivory, great streams of electricity, and in one direction only, may be generated. An instrument of this kind is called a magneto-electric, or dynamo-electric, machine, or simply dynamo, for brevity. Dynamos are multiple in form, and have reached great perfection. Dynamo is from the Greek *dunamis*, power, and is applied to electricity in motion, in contradistinction to that in the bound or static condition. No battery can be constituted to compete with them in

power; and they are much more economical and far less troublesome than batteries. Though differing much in model and variety of structure, all dynamos depend on the same principle of magneto-electric induction.

Several scientists have given their names to dynamos, but Gramme, of Paris, has given us by far the most celebrated and, indeed, useful one of them all. His instrument supplies a powerful current, and in a single direction, without the aid of commutators. Instead of an electro-magnet or other armature revolving before and in the immediate vicinity of the poles of a permanent magnet, the Gramme instrument has a wheel revolving vertically between the arms of a vertical permanent magnet. This wheel acts the part of armature, and is composed of an annular band of soft iron, wound around with several separate bobbins of insulated copper wire, whose ends terminate in radial copper bands insulated from each other. This armature acts the part of a combination battery, each bobbin performing the office of a separate cell having its positive and negative poles. During the revolutions of the wheel, the electricity is carried off from each side of the vertical line by wire brushes. The vertical is the dividing line between the two halves

of the circuit. A constant, steady, powerful current of electricity is thus generated.

The superiority of the Gramme dynamos rests in the low rate of speed necessary, and the freedom from commutators. Other dynamos require in the neighborhood of two thousand revolutions in a minute for effective work, causing thus a rapid heating up and wearing away of the machine. The Gramme dynamos can do all necessary work with a speed of three hundred revolutions in a minute, and generate a constant, even current, without commutators.

Probably the greatest scientific discovery of the last half hundred years is that the Gramme machine is reversible, and can be used as an electro-motor, as it is called. If two dynamos are so employed that the current from the armature of one may pass into the armature of the other the electricity generated by the motion of one will move the other. The dynamo may thus be used as a motive force, or electro-motor. Dynamos are so used to work machinery and run cars.

One of the recent and most useful discoveries of science is storage of electricity. It may be considered the greatest scientific achievement of the last quarter of a century. By the storage of elec-

tricity is meant the accumulation of a quantity of electric energy to be afterwards used at convenience. A storage-battery, called also a secondary battery, is an apparatus for transforming electricity.

The storage of electricity is not the actual gathering up of the fluid itself, as is done in the Leyden jar, or prime conductor, but the storing up of energy. When we wind up the spring of a clock, the force or energy requisite to do so is stored away, to be used afterward in running the clock. When we turn a crank to draw up the iron hammer of a pile-driver, we have so much energy stored away, to be employed in driving down the pile. So when, by the force of the electric current, we separate substances that have a great chemical affinity, the force being removed, these substances combine again, regenerating the same quantity of electricity that it required to separate them.

In mechanics it is often desirable to transform force into speed, or again speed into force. So, in electricity tension may be transformed into quantity, and quantity again into tension. The very life of the secondary, or storage, battery hangs on the principle, "To every action there is an equal and contrary reaction." Without reaction, we would have no storage of energy. In a Daniell's

cell zinc is eaten away, and pure copper deposited. By forcing a current of electricity back through the cell, the copper will be eaten away, and zinc deposited. In the deposition of the pure zinc we actually store energy; for, when the pressure is removed, the affinity of the oxygen for the zinc, being free to assert itself, will cause their reunion, and so will generate the same quantity of electricity that was required for the deposition.

The chemical affinity of the zinc for the oxygen is called its polarization. The force which separates the zinc from combination is called the electro-motive force; and the zinc's tendency to resist this force, or indeed its polarization, is called its counter-electro-motive force. The storage of electricity is the overcoming of this polarization, or counter-electro-motive force.

A storage-battery consists of two plates of lead placed in a vessel containing acidulated water. A current of electricity is sent, by means of an ordinary galvanic battery, from one plate of lead to the other. The current decomposes the water, sending the oxygen to one plate and the hydrogen to the other. The oxygen combines with the lead, forming peroxide of lead; and the hydrogen, reaching the other plate, decomposes any salt of lead it

may find there, precipitating pure lead, or otherwise escaping in the form of gas. The current is then reversed, and driven through the arrangement in the opposite direction. The current is thus reversed several times, in order to prepare the storage-battery, by making the surfaces of the lead plates porous, and so capable of holding a great quantity of peroxide of lead.

If the lead plates be connected by wire, after the battery has been charged the oxygen that had been forcibly driven from its combination in the liquid seeks to recombine, just as a stone forcibly lifted from the earth seeks to return, and the effect of this tendency of the oxygen is to generate an electric current in the opposite direction to the original one. This is the current that has been stored, and is to be utilized as storage.

Gaston Planté, a Catholic of Brussels, made the first storage-battery in 1859. It consisted of two sheets of lead, about three and one quarter feet square, rolled in a cylinder, and placed in a jar filled with dilute sulphuric acid. Strips of felt were placed between the lead sheets. He prepared his battery for use, by sending the current from three Grove cells through it several times in opposite directions. He then charged it, and permitted

it to so stand for a short time; he finally discharged it, and it was ready for use.

When the storage-battery is charged, and its poles connected, it works like any other battery. The metallic lead, combining with the acid, forms sulphate of lead; the liberated hydrogen takes the oxygen from the peroxide of lead on the other plate, forming water. When both the lead plates are reduced to the same condition, the battery is discharged.

The invention of storage, or secondary, batteries and the application of the Gramme machine as an electro-motor, taken together, may soon supplant steam in commerce. For these two great features of recent practical science we are indebted to two Catholic gentlemen, Gramme and Planté.

CHAPTER XXIII.

Other Catholic Electricians.

JEAN BAPTISTE BIOT was a great Catholic physicist of the first half of this century. He was a member of the French Academy, and professor of physics in the Collége de France. He contributed much to the advancement of electric science, and particularly in practically verifying the magnetic theory of Coulomb. In this connection, he demonstrated that on an elliptical spheroid the thickness of the fluid in the direction of the radius would be as the distance from the center.

The immortal Descartes, the father of "Analytical Geometry," labored zealously in the field of magnetism, and attempted to explain magnetic phenomena by the doctrine of vortices, or ethereal currents. If a magnet be placed among iron filings, these arrange themselves in curved lines, which proceed from one pole of the magnet to the other. It was not difficult to conceive these to be the traces

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of currents of ethereal matter which circulate through the magnet, and which are thus rendered sensible even to the eye. This theory of Descartes, though successful enough to be awarded the prize of the French Academy of Sciences for the year 1746, was soon superseded by the Coulombian theory.

The electric spark from a living body was first observed by the Abbé Nollet.

Nollet says he "shall never forget the surprise which the first electric spark ever drawn from the human body excited, both in M. Dufay and in himself." Soon after his discovery, Nollet sent the shock through a circle of one hundred and eighty men of the guards, in the presence of the king of France.

In the early construction of telegraph lines, two wires were used to connect the stations. Afterwards the earth was substituted for the returning wire. The Abbé Caselli made some very striking experiments to show that the earth acted the part of a great electric reservoir, rather than that of a conductor. Caselli invented the pan-telegraph, or electro-chemical copying telegraph. In 1856 he first experimented with it in Florence, Italy. For several years following he devoted himself to the

improvement and perfection of his invention, and in 1865 it was introduced into practical service both in France and Russia.

Léon Foucault, a French Catholic, was one of the greatest physicists of this century. Although he devoted himself principally to optics, and did his greatest work in that science, still he did much for electricity, and invented the first electric lamp, in 1844.

When the wire joining the poles of a strong galvanic battery, or Gramme machine, is severed, and the ends only slightly parted, the current still continues to flow, forcing its way through the intervening air. The resistance of the air, however, produces the most intense heat and light. So great is the heat that it fuses platinum as readily as a candle-flame melts wax. It will be easily understood that the light and heat cease almost immediately after the parting of the ends of the severed wire, because the wire itself is so rapidly consumed by the intense heat that the distance between the ends grows quickly so great as to prevent the passage of the current. Carbon is the only substance that resists fusion by the heat of the voltaic arc, as it is called. So that carbon electrodes, or points, must be used to sustain the light for any length of time.

Previous to 1844 the electric light had occasionally been used in laboratory experiments. In these experiments the light lived but a very short time, as the electrodes used were made of pencils of soft wood-charcoal, which wasted rapidly. Foucault substituted for this soft charcoal the hard gas-carbon that is found deposited in the interior of retorts used in manufacturing illuminating-gas. Even this hard carbon was found to waste away slowly, the positive electrode diminishing twice as fast as the negative. The carbon is not burned, but it seems that its particles are carried over from the positive to the negative pole, thus, in a manner, forming a conductor for the passage of the electric current. Foucault contrived mechanism to automatically regulate the distance between the carbon points. By keeping the electrodes at a uniform distance, he prevented the rupture of the current and obtained a continuous flame. Foucault's regulator consisted of two systems of automatic wheel-work, one for bringing the carbon points together when it was wished to start the light, and the other for separating and maintaining them at the proper distance. This apparatus of Foucault was the first electric lamp.

For the electrodes used by Foucault the carbon

was sawed into slabs, and then into pencils. This was both expensive and laborious. Great improvements were soon made in the manufacture of the pencils, for, while the price was greatly reduced, they still remained sufficiently hard. The essential composition of these improved pencils is powdered carbon, mixed with pressed coke, lampblack, and tar. They are now molded instead of being cut. The first and most famous manufacturer of these carbons was M. Carré, a French Catholic.

Another Catholic electrician known to fame is Nobili. He made many very interesting experiments in animal electricity, and left to his successors many most important facts relating to this branch of electric science. He devised the thermo-electric pile, or battery, consisting of alternate layers of bismuth and antimony. This pile of Nobili is of great utility in detecting the minutest changes of temperature, and is destined to play an important part in physiological researches. Among the names of Catholic electricians, those of Melloni and Dr. Antonio Pacinotti are conspicuous.

CHAPTER XXIV.

Chemistry.

OF all the nations of antiquity, the Egyptians had the fairest knowledge of chemistry. They excelled in the reduction of metals from their ores, making metallic alloys, and working metals. They were skilled in dyeing, and in the preparation of mordants.

The Chinese also were early acquainted with many chemical facts. Early in the eighth century, the Arabs began to study chemistry with great avidity, and speedily carried a portion of their knowledge into Europe. This was the tiny origin of European alchemy, which rapidly grew into gigantic proportions and continued to flourish for a thousand years.

Alchemy had the twofold aim of the transmutation of the baser metals into silver and gold, and the indefinite prolongation of human life. There was a really meritorious class of alchemists, who paved the way for genuine chemistry. But an-

other class, composed of designing knaves who had recourse to quackery and imposture, to dupe the credulous and avaricious, brought the name of alchemy into disrepute.

The domain of chemistry is an extensive one indeed. "Nature is composed of certain elementary bodies or elements. The knowledge of these bodies, of their mutual combinations, of the forces by which these combinations are brought about, and of the laws in accordance with which these forces act, constitutes chemistry." This is the definition of one of the very ablest of chemists. Chemistry, as a science, may be said to have taken its first real step in Germany early in the eighteenth century, with the appearance of the phlogistic theory of Stahl. Phlogiston was a hypothetical element, which, by combining with a body, rendered it combustible; and which, by its disengagement from the body, occasions combustion, leaving a residue of an acid or an earth. Combustion, according to the phlogistic theory, was a decomposition, a loss of some element, and consequently a decrease in weight. It is now known that the very contrary is true; that in combustion an element is added, instead of one being taken away. The phlogistic theory formed an epoch in chemistry.

The next great step, or rather leap, in chemistry was caused by the Lavoisierian theory, or the theory of oxygen. This was truly the greatest epoch in the history of chemistry. There probably never was produced such a complete revolution in any science as this theory of Lavoisier produced in chemistry. Its beauty, striking truth, and simplicity carried all before it. To this very day, the system of Lavoisier remains as the skeleton of the science. Lavoisier showed that, in the calcination of metals in air, the metal acquires as much weight as the air loses. He also showed that atmospheric air consists of pure or vital air and of an unvital air, which he called *azot* and which is now known as *nitrogen*. The vital air he discovered to be the agent in combustion, respiration, calcination, and acidification; and that all these processes consisted in a decomposition of the atmospheric air, and a fixation of the pure or vital portion of it. Where, according to the phlogistic theory, phlogiston was subtracted, he found that this vital air was added; and where the phlogiston was added, the vital air subtracted. He gave the name of oxygen to "the substance which thus unites itself with metals to form their calces (ores), and with combustible substances to form acids."

In harmony with the oxygen theory, Lavoisier and his friends constructed a nomenclature, which was then extremely necessary. This nomenclature soon made its way into general use. For half a century it was universally employed, and was found to be more effective and useful than any nomenclature in any science had ever been before.

The next great era in chemistry was introduced by the atomic theory of an English Quaker, the meek and patient Dalton. This theory announced that matter consists of ultimate particles, or atoms, incapable of division. These elementary atoms combine, in certain fixed proportions, to form compound bodies. The proportions in which the elements combine depend on the weight and not the volume, and are regulated by these four laws: "The law of definite proportions, or a compound of two or more elements, is always formed by the union of certain definite and unalterable proportions of its constituent elements; the law of multiple proportions, which requires that when two bodies unite in more proportions than one, these proportions bear some simple relation to each other; the law of equivalent proportions, according to which, when a body (A) unites with other bodies (B, C, D), the proportions in which B, C, and D

unite with A shall represent in numbers the proportions in which they will unite among themselves, in case such union takes place; the law of the combining numbers of compounds, by which the combining proportion of a compound body is the sum of the combining weights of its several elements."

The application of the galvanic current to the resolution of bodies into their constituents introduced electro-chemistry. This field of chemistry has been wonderfully developed by the most patient and thorough research. The great principle of the identity of electrical and chemical action has been completely established.

Chemistry, at the present time, is in altogether a transitional state. This is due principally to great advances made recently in organic chemistry by Dumas and his associates. A new nomenclature is being constructed, but is as yet in an unsettled condition. The atomic theory, however, with but slight alteration, still holds its own.

CHAPTER XXV.

Lavoisier.

NTOINE LAURENT LAVOISIER, the founder of modern chemistry, was born in Paris, in August, 1743. The name of this Catholic physicist is, beyond dispute, the greatest in chemistry; and it is safe to say that none of the great sciences is as much indebted to a single man as chemistry is to Lavoisier. Lavoisier was a thorough enthusiast in the pursuit of chemistry; his very heart was in the science.

His father, being a man of means, was able to permit his son to devote untrammeled his time and energies to his favorite pursuit. Lavoisier gathered around him some of the most brilliant chemists of the time, and together they prosecuted in his laboratory a series of most successful experiments.

One of the greatest merits of Lavoisier, as it is of every inductive philosopher, was his power of generalization. Indeed, he possessed it in a most

remarkable degree. Taking his own and his predecessors' experimental discoveries, he generalized their results into his theory of oxygen.

Lavoisier's was the extraordinary merit of introducing the balance into the laboratory, and so causing the great importance of quantitative analysis to be recognized. By means of this analysis, he perceived that the increase of weight acquired by a given weight of metal when oxidized disproved the whole theory of phlogiston. He showed that the products of combustion weigh exactly as much as the sum of the weight of the substance consumed, plus the weight of the matter absorbed from the air. He also demonstrated the important truth, that wherever an increase of weight occurs combination must have taken place, and that the weight of the product of such combination is equal to the sum of the weights of its ingredients; while loss of weight is due to the separation of ponderable matter.

His original experiment, in which he proved that the increase of weight in an oxidized metal is due to its absorption of gas, was made with tin. He placed a given weight of metallic tin in a sealed retort, and weighed the whole. He then applied heat to the retort until the tin was melted,

and more or less oxidized by absorbing the air in the retort. When he again weighed the retort, he found the weight unchanged. But, on removing the seal and opening the apparatus, the outside air rushed in to replace the absorbed air. He then weighed the retort, and found an increase of weight equal to the amount of air absorbed by the tin in its process of oxidation.

Lavoisier distinguished among chemical elements a number that ought to be regarded as simple, such as oxygen, hydrogen, and nitrogen; and also originated the method, still in use, of decomposing organic substances. He and his associates formed a nomenclature founded on his oxygen theory. In this nomenclature, naturally enough great prominence is given to oxygen, as it was thought by the founders that most of the known acids and bases contained it. Indeed, the compounds of oxygen formed the basis of the system. In this nomenclature the name of a compound generally indicates its composition. Thus, the name oxide of iron indicates that that substance contains oxygen and iron. When metalloids, as they are called, unite with oxygen to form acids, the termination marks the character of the acid. Thus, sulphur combined with oxygen in two different proportions

forms two acids, the sulphur*ous* and sulphur*ic*; and these acids form with bases respectively sulph*ites* and sulph*ates*. Similarly as oxygen forms oxides, chlorine forms chlorides; bromine, bromides; iodine, iodides; fluorine, fluorides; nitrogen, nitrides; carbon, carbides or carburets; sulphur, sulphides or sulphurets; selenium, selenides or seleniurets; phosphorus, phosphides or phosphurets. Chlorine with oxygen forms chlor*ous* and chlor*ic* acids; and these with bases, chlor*ites* and chlor*ates*, and so on.

The learned Whewell pays this tribute to the greatest of chemists: "The originality of the theory of oxygen is proved by the conflict, short as it was, which accompanied its promulgation; its importance is shown by the changes which it soon occasioned in every part of the science. Thus Lavoisier, far more fortunate than most of those who had, in earlier ages, produced revolutions in science, saw his theory accepted by all the most eminent men of his time, and established over a great part of Europe within a few years from its first promulgation. In the common course of events, it might have been expected that the later years of his life would have been spent amid the admiration and reverence which naturally wait upon the patri-

arch of a new system of acknowledged truths. But the times in which he lived allowed no such euthanasia to eminence of any kind. The democracy which overthrew the ancient political institutions of France, and swept away the nobles of the land, was not, as might have been expected, enthusiastic in its admiration of a great revolution in science, and forward to offer its homage to the genuine nobility of a great discoverer. Lavoisier was thrown into prison on some wretched charge of having, in the discharge of a public office which he had held, adulterated certain tobacco; but in reality for the purpose of confiscating his property. In his imprisonment, his philosophy was his resource; and he employed himself in the preparation of his papers for printing. When he was brought before the revolutionary tribunal, he begged for a respite of a few days, in order to complete some researches, the results of which were, he said, important to the good of humanity. The brutish idiot whom the state of the country at that time had placed in the judgment-seat told him that the republic wanted no sçavans. He was dragged to the guillotine, May 8, 1794, and beheaded, in the fifty-second year of his age; a melancholy proof that, in periods of political ferocity, inno-

cence and merit, private virtues and public services, amiable manners and the love of friends, literary fame and exalted genius, are all as nothing to protect their possessor from the last extremes of violence and wrong, inflicted under judicial forms."

CHAPTER XXVI.

Other Catholic Chemists.

HE alchemists thought that all the metals were composed of two constituents, sulphur and mercury, and that the nature of the metal depended upon the relative quantity and purity of these components. The leading tenet in the alchemist's creed, the doctrine of the transmutability of other metals into gold and silver, sprung from the belief that there were very few elementary bodies in nature. It is curious that the most advanced chemistry of the present day is going back to alchemy. Our leading speculative chemists are growing more and more of the opinion that many substances, hitherto regarded as chemically distinct, are only the same substance under a different arrangement of its component particles. They think that the number of really distinct elements is very few indeed. This belief has arisen from the study of the phenomena of allotropy. The allotropic condition of a body is the appearance of

the very same body under a different form altogether. Thus carbon appears as the diamond, and also as charcoal and lampblack. Phosphorus, sulphur, and oxygen, among other elements, are remarkable for their allotropic conditions, and, though remaining the same substance essentially, appear under different forms.

It was by the gradual collection and explanation of chemical facts that chemistry became a science. Many of these facts have come down from the earliest times. Whosoever has added, by his discovery, to the common treasury of these facts, whether he is known as chemist or alchemist, has helped the cause of chemistry, and is entitled to the gratitude of mankind.

Among the greatest of the alchemists was Roger Bacon, a Franciscan monk (1214–1284), and a native of Somersetshire, England. This Friar Bacon was a most extraordinary genius, and is said to have made many chemical discoveries. He speaks in such a manner of an inextinguishable fire as to leave the impression that he was acquainted with phosphorus. He certainly knew the composition of gunpowder, for he distinctly says that thunder and lightning could be imitated by means of saltpeter, sulphur, and charcoal.

A contemporary of Bacon was Albertus Magnus (1205–1280), and an alchemist of the highest renown. Albertus was a great master of the practical chemistry of his time. He believed that water was the most elementary of bodies, and nearer the soul of nature than any other substance.

Another of the great alchemists was Raymond Lully (1234–1315), a native of Majorca, and called "the enlightened doctor." His is the credit of having first employed chemical symbols.

A great name in alchemy is that of Basil Valentine (b. 1394). His practical knowledge of the chemistry of his day was very great, and he is regarded as the founder of analytical chemistry. He introduced the use of antimony into medicine, and considered salt, sulphur, and mercury as the sole components of all metallic bodies.

Agricola (1490–1555) greatly excelled in that department of chemistry known as metallurgy. He is, indeed, regarded as the founder of this branch of the great chemical science. He pursued his specialty with great enthusiasm and industry, and became exceedingly distinguished in it.

Among the early chemists, the Catholic name of Van Helmont (1577–1644) is one of the most famous. His is the merit of having introduced the

term gas into chemistry. He describes many different kinds of gases, and distinguishes them from watery vapor. He rejected many of the tenets of the alchemists, and refused to admit that sulphur, mercury, and salt were the elementary ingredients of all substances, and more especially of animal bodies. He looked upon water as the primary element of all things.

It is conceded that France has done more for the philosophy of chemistry in recent years than any other country. And the great French chemists have nearly all been children of the Church. Among them, the name of Dumas must be placed with the very first. His labors in organic chemistry have been productive of the most important results. He was the author of the theory of "substitutions," according to which hydrogen may be replaced, equivalent for equivalent, by some other element or group of elements, while the properties of the original substance remain usually unchanged. He invented an ingenious apparatus for finding the specific gravity of vapors, which has been of great value to chemists. His investigations upon ether, volatile oils, and wood-spirit are among his most important ones.

Antoine César Becquerel's researches in electro-

chemistry were so numerous and important that he is justly considered the creator of this branch of chemical science. He applied electro-chemistry to the reproduction of mineral substances, and to treating by the humid way silver, lead, and copper ores. Aluminum, silicon, glucinum, galena, malachite, calcareous spar, dolomite, metallic phosphates, crystallized silica, and numerous metallic sulphurets are among some of the new substances Becquerel succeeded in obtaining, through the agency of electricity. The labors of this great Catholic chemist were extraordinary, and his discoveries very many and very valuable.

In the physico-chemical school, the discovery by Dulong and Petit of the relation between the specific heats and equivalent weights of substances is especially valuable. A devout French Catholic, Michel Eugène Chevreul, is probably the greatest living chemist. The centenary of this remarkable man was celebrated by the French people with the most prodigious enthusiasm on the 31st of last August. His services to chemistry have reached all its departments and been eminently practical.

Chevreul was the first practical expositor of that wonderful substance, glycerine, so useful in soap-manufacture, medicine, and commerce generally.

He achieved his greatest successes, however, in the art of dyeing and the practice of candle-making. He devoted himself with great diligence to the investigation of animal fats, and nothing of importance in this connection escaped his acute observation. To his researches we owe, among other things, stearine candles.

He gave long and earnest study to the subject of color, and particularly in its relations to harmony and contrast. His observations on colors are developed in one of his chief works, "The Principles of Colors in their Application to the Arts."

Indeed, nothing in chromatics was unworthy of his notice. He laid down rules for the distribution of colors in carpets, paper-hangings, mosaics, and printed calicoes; in the decorations of the interiors of churches, museums, galleries, and libraries. This great philosopher has done much toward refining the tastes and ameliorating the social condition of his fellow-beings.

M. Chevreul is a pious Catholic with a most sincere faith. A worthy priest relates the following instance of his devotion to the Blessed Virgin: "Some three or four years ago, the savant was passing through the little town of Dourdan, numbering about two thousand souls. In the afternoon of the

same day the curé, entering his church, perceived an old man kneeling before Our Lady's altar, saying his Rosary. Not wishing to disturb the stranger's devotion, he simply bowed, and retired to say his Office. When the old gentleman had finished his beads, he went up to the priest. "Monsieur le curé," he said, courteously, "you are perhaps astonished to find a stranger in your church at this hour. I am M. Chevreul; I have missed the train, and while waiting for the next I thought I could make no better use of my time than by coming here to pray to Our Lady."

Chemistry being a French science is particularly rich in great Catholic names; and to undertake to do them justice in a few short chapters would be utterly futile. It is therefore understood that but a meagre relation of the achievements of a few of the very greatest chemists whose contributions were such as to form epochs in the science has been here attempted.

CHAPTER XXVII.

Mineralogy.

MINERALOGY is a classificatory science, and teaches how to distinguish the different kinds of minerals. The science is confined to simple minerals, or homogeneous mineral substances. Some mineralogists have considered only the chemical composition of minerals, and were solely thereby influenced in their classification. Others regarded only their external characters, and in their classifying were governed accordingly. Recently, scientists have aimed at a combination of both these methods.

The greatest difficulty has been experienced in attempting a classification of the mineral kingdom on chemical grounds, owing to the boundless variety of the combinations of the elements and the almost invariable presence of foreign bodies, that often entirely change the character of the mineral. Hence the chemical classification is very far from satisfactory.

The most marked of the external characters of minerals is their crystalline form. By applying crystallography to the classification of minerals, and thus introducing into it geometrical relations and figures, mineralogy has been reduced, in great measure and as far as crystalline form is applicable, to an exact science.

The principle of crystallography, as assumed by Haüy, is that the same chemical elements, combined in the same proportions, will always exhibit the same crystalline form; and, reciprocally, that the same form and angles imply the same chemical constitution. There are many exceptions, however, to this rule. One is that of isomorphism, where one body can replace another in combination, without changing the crystalline form. The chemical composition may be changed, while the form of the crystal remains the same as before. Another remarkable exception is dimorphism, where the same compound has two different forms, as, for intance, the carbonate of lime, appearing as calc-spar and arragonite; these crystals, though the same compound, having entirely different shapes.

A crystal is any inorganic substance bounded by plane surfaces arranged with system and of homogeneous structure. There is a great variety of

crystalline forms. Crystallography treats of the form, structure, and formation of crystals. Nearly all inorganic substances are capable of crystallization. Bodies may be crystallized principally in three ways. The most ordinary way is by solution. Warm water has greater solvent powers than cold water. When a warm saturated solution of a salt is permitted to cool, a portion of the salt is precipitated in the form of crystals. Another mode of crystallization is to fuse the substance, such as sulphur, and then allow a portion of it to solidify. By breaking a part of the crust and pouring out the liquid, a number of crystals will be found lining the interior. The third process is by vaporization and subsequent condensation. Snow-crystals are obtained from the vapor of water, by its condensation.

Though there are some thousands of crystalline forms in nature, they can all be reduced to six geometrical classes. The first class is called the isometric, or monometric, and its crystals have three equal axes at right angles to one another. The second class is called dimetric, and has one variable axis and two equal axes, and all the axes intersect at right angles. The third class is the trimetric, and has three axes of unequal length, but

intersecting each other at right angles. The fourth class is the monoclinic, and has three axes which may be of unequal lengths, two of which are at right angles to each other, but the third axis is perpendicular to one of these, and oblique to the other. The fifth is the triclinic, and has all the axes of unequal length, and all are obliquely inclined to each other. The sixth class is the hexagonal, and has four axes, three in the same plane and inclined to each other at an angle of 60°, whilst the fourth axis is at right angles to the other three.

In each of the classes there is a fundamental form, the other forms included in the class being regarded as secondary. The fundamental forms are the cube, square, prism, right rectangular prism, oblique rhombic prism, oblique rhomboidal prism, and hexagonal prism. The following bodies, in the order of mention, are examples of each of these classes of crystals respectively: common salt, calomel, sulphur, carbonate of soda, sulphate of copper, and ice.

"The structure of crystals is often seen by lines on their surfaces, or by the ease with which the crystal splits in certain directions. Common mica

cleaves in leaves; galena breaks only in cubes, fluor-spar in octahedra, calc-spar only in rhombohedrons. This property is called cleavage. It does not exist in all crystals, and is not of equal facility in all directions. Thus, in mica cleavage is easy in one direction only; while in fluor-spar and calcite it is equally easy in three directions respectively."

The greatest name in mineralogy is that of René Just Haüy, the creator of the modern science of crystallography. By the indefatigable labors of a lifetime, he demonstrated the importance of crystalline form in the classifying of minerals. René Just Haüy, a native of Picardy, was an humble French priest. For fidelity to his conscience during the Reign of Terror he was thrown into prison. He was rescued on the very eve of the September massacres of 1792, by the devotion of his pupil, Geoffroy Saint-Hillaire, at the imminent peril of his own life. Haüy, early in his labors, recognized the invariability of the angles of crystals, notwithstanding the changes which their faces might happen to undergo. A happy accident, the dropping of a specimen of calcareous spar, led to his discovery of the importance of cleavage, and subsequently to

that of the true laws of crystallization. This latter discovery occasioned a new arrangement of minerals, and opened a new era in mineralogy.

The law of constancy applies only to what are known as the primitive forms of crystals. Many secondary forms are derived from the primitive ones. Haüy discovered the laws by which the secondary forms are derived from the primary. "The mathematical deduction of the dimensions and proportions of these secondary forms," says Whewell; "the invention of a notation to express them; the examination of the whole mineral kingdom in accordance with these views; the production of a work in which they are explained with singular clearness and vivacity, are services by which Haüy richly earned the admiration which has been bestowed upon him. The wonderful copiousness and variety of the forms and laws to which he was led, thoroughly exercised and nourished the spirit of deduction and calculation which his discoveries excited in him. The reader may form some conception of the extent of his labors, by being told that the mere geometrical propositions which he found it necessary to premise to his special descriptions occupy a volume and a half of

his work; that his diagrams are nearly a thousand in number; that in one single substance (calc-spar) he has described forty-seven varieties of form; and that he has described one kind of crystal (called by him *fer sulfuré parallélique*) which has one hundred and thirty-four faces."

CHAPTER XXVIII.

Botany.

BOTANY, another of the classificatory sciences, treats of the vegetable kingdom. The domain of this science is truly vast. Botanists have already discovered and described one hundred and twenty thousand species of plants, and still there remain mighty regions of the earth whose flora is entirely unknown. The number of the votaries whom this charming science has tempted to climb the ladder of fame is legion. Probably no other science has had so many and so devoted students.

Botany is a very old science, and its birth may be considered as coeval with that of the race. Botany rejoices in the possession of three great names among the ancients, Theophrastus among the Greeks, the Roman Pliny, and Dioscorides of Anazarbus, Asia Minor. Theophrastus of Eresos wrote the first great book on botany in the fourth century B.C. Pliny has left us sixteen volumes on

plants. But of ancient botanical works, that of Pedanius Dioscorides of Anazarbus in Cilicia, Asia Minor, reached the greatest fame. Dioscorides, who wrote about 100 A.D., describes six hundred species of plants.

In all likelihood the three who have done most for the modern science were Cæsalpinus, Linnæus, and Jussieu. Of these, two were Catholics, Cæsalpinus and Jussieu.

Andreas Cæsalpinus of Arezzo in Italy was the first to construct a system of botany, or to invent a method which distributed into consistent and distinct divisions the whole vegetable kingdom. Cæsalpinus was the father of modern botany, and his book, "De Plantis" (1583), introduced its first great epoch. Cæsalpinus founded his system on the fructification of plants. "All science," says Cæsalpinus, "consists in the collection of similar and the distinction of dissimilar things. . . . Let us now endeavor to mark the kinds of plants by essential circumstances in the fructification. . . . In the constitution of organs three things are mainly important—the number, the position, the figure." The whole system of Linnæus rests on this arrangement of Cæsalpinus. Cæsalpinus was born in Arezzo, in 1519, became professor in the univer-

sity of Pisa, and afterwards physician to Pope Clement VIII. He was a great philosopher, and contributed material aid toward the progress of many other sciences besides botany.

The two great epochs in botany succeeding the Cæsalpinian were marked respectively by the systems of Linnæus and Jussieu. The system of Linnæus is called the artificial, or sexual, system, and is based upon the characters of certain external parts of a plant, without any regard to the connection of these same characters with the plant's life or purpose of existence. The characters chosen by the great Swede on which to build his system are the stamina and pistils—their number, position, and other circumstances. No artificial classification could be more perfect than that of Linnæus, and his system met with great and immediate popularity. Students flocked to him from all countries, and he became wonderfully famous, and certainly did great things for botany. Still, no artificial system, however perfect, can answer the highest purposes of science. True science looks beyond the artificial and yearns for the natural. The Linnæan system is now obsolete.

In the natural system both the external characters and internal organization of the plant are alike

considered, so that all the real affinities subsisting in the vegetable world are exhibited. In forming a natural system, great difficulties had to be encountered, owing to the immensity of the field and the almost infinite variety of the individuals, and consequently no natural system can be entirely perfect.

Bernard de Jussieu, in his arrangement of the plants in the garden of the Trianon, Paris, devised a "Natural Method." The aim of the Jussieuan system is to gather together all such plants as are allied in all essential points of structure, and to take into account the true affinities of plants, on a comparison of all their organs. Its first author was Bernard de Jussieu. It was perfected and published by his nephew, Antoine Laurent de Jussieu. The great work of Antoine Laurent, "Genera Plantarum secundum Ordines Naturales Disposita," published in 1789, according to Cuvier, holds the same place with regard to botany that the experiments of Lavoisier do to chemistry. From the date of this work, the natural system was firmly established as the true basis of botany. It marks the greatest epoch in the history of the science.

"The object of the Jussieus," says Whewell, "was to obtain a system which should be governed

by the natural affinities of the plants, while, at the same time, the characters by which the orders were ostensibly determined, should be as clear, simple, and precise, as those of the best artificial system. The main points in these characters were the number of the cotyledons and the structure of the seed; and subordinate to this, the insertion of the stamina, which they distinguished as epigynous, perigynous, and hypogynous, according as they were inserted over, about, or under, the germen. And the classes which were formed by the Jussieus, though they have since been modified by succeeding writers, have been so far retained by the most profound botanists, notwithstanding all the new care and new light which have been bestowed upon the subject, as to show that what was done at first, was a real and important step in the solution of the problem."

Among the greatest names in botany must be mentioned those of the pious Catholic brothers, Charles and Louis René Tulasne, lately deceased. They are the great authorities on vegetable fungi. On the occasion of the death of Louis, Dr. Vidal wrote to the President of the French Academy as follows: "You will have at Paris all the information regarding his scientific work, but what will

never be known is the amount of good which he did to those about him. M. Tulasne lived very retired in the country; he received all persons with the same affability, but one saw that to interest him actively it was necessary to point out to him those who were unfortunate and in need of consolation, and then his goodness and charity were equally inexhaustible. Aided by his brother, Dr. Tulasne, who died last year, he established charitable institutions pretty nearly everywhere in this region. His life, so well spent, may be summed up by saying that he did good—nothing but good, and always good."

CHAPTER XXIX.

Physiology.

THE science of physiology treats of organs and their functions. The word itself is derived from two Greek terms, and literally signifies a discourse concerning nature. The growth of the science has been slow, but constant, from the earliest antiquity. The science is one of vastness and complexity, and every generation has added something to its improvement. It has always claimed a great number of ardent cultivators, and made great progress even among the ancients.

The names of Hippocrates of Cos, Asclepiades of Bithynia, and the great Stagirite attained great fame in physiological science. But by far the greatest master of physiology among the ancients was Claudius Galen of Pergamus (A.D. 203). Galen had a sound and clear knowledge of the general structure of the animal frame. For more than a thousand years he was the undisputed authority in

anatomical science, and during that vast period was universally referred to as "the master."

The first to seriously call in question the views of Galen was Andreas Vesalius, a Catholic professor in the great university of Padua in the sixteenth century. Vesalius' charge against Galen was a just one, that in his dissections the master used animals instead of the human body. The great work of Vesalius, "De Corporis Humani Fabrica," was published in 1543. We have the testimony of Cuvier that the three Catholic professors, Vesalius, Fallopius, and Eustachius, were the founders of modern anatomical science.

Gabriello Fallopius of Modena was a pupil of Vesalius, and became a professor at Padua. His great work, "Observationes Anatomicæ," was published in 1561. He is noted chiefly for his treatise on the structure of the ear, one of whose tubes still bears his name.

Bartolommeo Eustachius of Salerno is best known for his anatomical descriptions of the ear and teeth. The Eustachian tube, connecting the ear and throat, is named for him. His work, "Tabulæ Anatomicæ," was not published until 1714, the original text having been lost.

Realdus Columbus, a pupil of Vesalius and also

a professor at Padua, was the discoverer of the pulmonary circulation of the blood. This discovery is mentioned in his work "De Re Anatomica" (1559). Cæsalpinus explained more fully this pulmonary circulation, and may be almost said to have discovered the great circulation, as he mentions among his observations the swelling of the veins on the side of the ligature away from the heart.

Fabricius of Acquapendente, another of the Paduan professors, discovered that the valves of the veins are all turned towards the heart. Morse invented the telegraph by combining and utilizing the discoveries of others. So the discoveries of these Catholic professors were the means of enabling Harvey to discover the great circulation of the blood. This is written of Harvey, not in the least to subtract from his glory, but to give a just meed of praise to his predecessors and great coadjutors in the advancement of physiological science. Harvey was not a Catholic, still he received his tuition from Fabricius of Acquapendente in the great Paduan university. Harvey's name is the greatest in modern anatomy.

Spallanzani made many interesting experiments on the subject of digestion, favoring the opinion that it is a solution of the food by the gastric juice.

The laborious researches of Malpighi of Bologna did invaluable service for physiological science, he being the first to introduce the microscope into anatomical examinations. His is the extraordinary merit of discovering the capillary circulation of the blood from the arteries to the veins, and thus completing Harvey's great discovery. His great work on the Chick was published in 1673.

Santorini, whose physiological researches were mainly confined to the nervous system, explained the action of a part of the brain upon the nerves of the opposite side.

One of the greatest laborers on the nervous system was Bichat, who made a most important step in the knowledge of the nerves when he established the distinction between a ganglionic system and a cerebral system. Johannes Müller proved himself a brilliant physiologist in his great work, "Manual of Physiology" (1833).

Among other distinguished Catholic cultivators of anatomy and physiology were Francis Redi of Arezzo, Morgagni, Lancisi, Paré, Desault, Bellingeri, and Claude Bernard.

Though a classificatory science, zoology properly comes under the head of physiology, because its subjects are classified according to a natural or

physiological plan. An attempt was early made to classify zoology artificially, or according to the external parts, similarly to the Linnæan plan in botany. But this was soon abandoned.

Cuvier was the first to arrange the animal world after a plan based on the animal's structure. He argued that the whole animal kingdom is modeled on four plans or forms. The four great types are the vertebrata, mollusca, articulata, and radiata. The vertebrates include all animals having an internal skeleton, with a back-bone for its axis. The articulates embrace all animals whose body is composed of rings or joints. Mollusks, or soft animals, have no bony skeleton. The division of radiates is composed of animals whose organs radiate from a center. Cuvier deserves the first place in zoology for the importance of his work. Cuvier, though a non-Catholic, was a devout and firm believer in the Creator. Not only his belief but his philosophy was firmly fixed on the acknowledgment of a creative purpose as well as a creative power in nature. And indeed Whewell demonstrates in the Bridgewater Treatise "that those who have been discoverers in science have generally had minds the disposition of which was to believe in an intelligent Maker of the universe; and that the scientific spec-

ulations which produced an opposite tendency were generally those which, though they might deal familiarly with known physical truths, and conjecture boldly with regard to the unknown, did not add to the number of solid generalizations."

In respect of the excellence of their work in zoology, two Catholic names must be placed immediately after Cuvier's—those of Buffon and Daubenton. Their great joint work, "Histoire Naturelle," must always be justly regarded as one of the greatest contributions to zoological science.

CHAPTER XXX.

Geology.

GEOLOGY, as a science, is still in its early youth, and indeed it is through courtesy that it is admitted into the scientific category. Nearly the whole of the mighty crust of the globe remains unexplored by geologists, and the organic fossils of vast regions are entirely unknown. And concerning even the comparatively minute portion that has been geologically analyzed the facts are few and our knowledge meager.

The furious and unseemly strifes of the Vulcanists and Neptunists, together with the ridiculous claims set up for it while it was still in its swadling clothes, brought geology into disrepute. But a better spirit now animates its students, who, wisely steering clear of hypotheses, content themselves with a patient pursuit of facts.

Geology, in its usual and restricted sense, is a history of the structure of as much of the earth's

crust as is accessible to man's observation. The crust of the globe has left its own historic record indelibly traced upon its stony strata. This rocky envelope is far from being homogeneous, it being the resultant of many contrary and conflicting forces. So that, naturally, this geological record is exceedingly obscure, much more so even than the enigmatic sculptures of Ninive and Egypt.

The rocky formations of the earth's crust are divided into the igneous and aqueous. The igneous, or unstratified, rocks are supposed to have been produced by fusion. The aqueous, or stratified, rocks seem to have been formed through the agency of water, by a chemical and sedimentary process.

Lithologists read the chronological order of terrestrial creation from the character of the rocky formations themselves. Lithology is the science of rocks. The paleontologists read this order from the nature of the fossil remains found buried in the strata. Paleontology is the science of fossils. It is deemed that the fossils have kept a much more reliable record, chronologically, than the stones. The character of the fossil very accurately defines the period in which its embedding strata were formed, as the order of the animal succession is fairly well established. On the other hand, it is very difficult to

trace, with any degree of accuracy, the correct order of their succession from the character of the stony formations themselves; they are so twisted together and interwoven, having been metamorphosed by the agencies of heat, water, the atmosphere, and galvanism. Hitchcock defines a fossil to be the body or any known part or trace of an animal or plant, buried by natural causes in the earth; and hence a mold or mere footmark is a fossil.

The country of Galileo and Volta, the two greatest names in science, is the birthplace of geology. It is an Italian science; and, though other countries have materially added to its growth and symmetry, it must not forget its Catholic parentage. The celebrated painter of the greatest of all frescoes, the "Last Supper," Leonardo da Vinci, was one of the first to form a correct opinion of the fossil remains embedded in the rocky strata of the earth. He maintained that the fossil shells found in rocks are real shells, and that there have been real changes in the land and ocean. Da Vinci was led to his views on the subject of fossils from his observations made while superintending the digging of canals planned by him in the north of Italy. It is principally to this extraordinary man, the inventor of canal locks, and regarded by Humboldt as the

greatest physicist of the fifteenth century, and Friar Roger Bacon, that we owe that introduction of the experimental or inductive system into study that has brought modern sciences to their present proud perfection.

Following Da Vinci came Fracastoro, who, from observations made by him during excavations about the city of Verona, gave it as his opinion that fossil shells are real shells of animals once living on the globe.

Fabio Colonna (1592) was of the opinion that fossil shells had been left on land by the retiring ocean and were subsequently petrified.

Nicolaus Steno, the great Danish anatomist, a Catholic bishop, living the most of his life in Italy, was one of the very greatest contributors to the advancement of the young science of geology. In his great work, "De Solido intra Solidum naturaliter Contento" (1669), he was the first to distinguish between the primitive unstratified rocks containing no organic remains and the sedimentary aqueous fossiliferous strata. He was also the first to state that the fossiliferous strata were all originally deposited in horizontal beds. The subsequent twisting of these strata he attributes partly to eruption of subterranean vapors caused by internal heat,

and partly to the giving way of the underlying strata.

The Sicilian painter, Augustine Scilla (1670), published an illustrated treatise on the petrified remains of Calabria and Malta. Antonio Vallisneri of Modena, the great Italian naturalist, described (1721) the fossils of Monte Bolca, and tried to determine the territorial extent of marine fossils in Italy.

Vallisneri was succeeded by Father Spada (1737), Lazzaro Moro (1740), Cirillo Generelli (1749), and Donati (1750). It is generally conceded that the Italians have always been preëminent in geological investigations.

Buffon, Ampère, Sorignet, Bourgeois, Delauny, and Johannes Müller are Catholic names well known in the history of geological progress.

One of the liveliest sources of controversy among geologists is the theory of a central igneous fluidity. Many grave scientists believe that, with the exception of a very shallow crust, the whole interior of the globe is a fiery liquid ocean. In proof of this opinion, they instance thermal springs, volcanoes, earthquakes, and, particularly, the supposed regular and gradual increase in the temperature of all deep

mines, equal to 1° F. for every 55 feet of descent after the first 100 feet.

By the great care and delicacy employed by physicists in their observations in recent borings, together with the improved methods of measuring heat, they have found that the increase in the temperature as we descend from the earth's surface is often irregular; that sometimes there is no increase; and that frequently there is a decrease. So that the gradual increase of temperature is now given up.

It is an established mechanical law, according to Daniel, that an incandescent fluid mass must be in a constant state of circulation by the cooling of its exterior. The interior fluid mass of the earth ought to be in a constant whirl, if it is a cooling liquid. Dreadful tides would incessantly rise in this mighty igneous ocean, and flow around after the moon and sun. No crust could withstand the breaking of such tides. The cooling of this liquid mass would cause a continuous contraction of the globe, and consequently a shortening of the day. The nicest mathematical calculation shows that the day's length has not changed the hundredth part of a second in more than three thousand years. Al-

though there are certainly two sides to this question of central fluidity, the weight of evidence seems to favor the solidity of our planet.

The quondam conflict between geology and Moses has winged its flight to the home of the myths. There is the most perfect concord between geology and the cosmogony of the great Lawgiver. Moses, in describing the origin of things, had no intention of writing a treatise on science. He confined himself to a narration of such facts as suited his purpose, in giving a clear and succinct history of God's work in the creation, and so omitted many details that should be mentioned in a comprehensive work on the science of the earth. But the facts related by Moses are in absolute accord with the teachings of geology. "Geological observations are in perfect accordance with the Book of Genesis," says Cuvier, "in reference to the order in which all organic beings have been successively created." With regard to the length of the days of creation to be understood in Genesis, Faith determines nothing. We can hold the days to be indefinite periods, if we wish, without compromising Catholic doctrine. The early Fathers of the Church were the first to consider these days not as ordinary days. Particularly is this true of St. Augustine,

who declares "that we should not hastily pronounce on the nature of the six days of creation, nor assert that they were similar to our ordinary days."

We have an epitome of geology in these few expressive words of the Abbé Sorignet, in his "Sacred Cosmogony" (translated by Archbishop Kenrick): "Geology is able to assign the point when life began to appear on our globe and to deposit its products. This point is the epoch in which were formed the sedimentary primary, or transition, strata. Then life emanated from Creative Omnipotence, and from that moment the history of vegetable and animal productions is associated with that of mineral phenomena.

"If we descend through the series of rocks, in setting out from the uppermost strata, we find traces of life everywhere in the tertiary, secondary, and primary formations. We find that the lowest strata of the primary system become gradually bare of organic remains. The slate bearing on it impressions of terrestrial plants, and alternating with limestone which contains some marine fossils, degenerates into micaceous schist, this into gneiss, and this last into granite. Arrived at this point, we no longer find clay-schist, or sand, or sandstone; no

more lime, nor carbonic substances; in fine, no more deposits formed by the water, nor organized beings; but masses of granite enveloping the whole globe are everywhere found below the sedimentary rocks, in the hollows of which these rocks were deposited.

"There was, then, a time when this immense granite basin was empty; when the waters—this first condition of life—did not exist on the surface of the globe,—void and uninhabited. It was then this great basin that received at the beginning the vegetable species and the sea-animals. It was on a surface in relation with the immense inequalities of the granite that were produced the fluviatile and terrestrial species. There was their and our first cradle.

"Thus all things have had a beginning. The proof of this great fact, the announcement of which opens with such sublimity the history of the world by Moses, has been found by geology in the entrails of the earth. From the bottom of abyss, whither the hand of God had brought and accumulated their remains, the dead have come and deposed to the truth of the sacred record of Genesis.

"Geology goes still farther: after conducting us as it were to the cradle of life, it makes us assist at its

last moments; it shows us the tomb of thousands of animal and vegetable species; and confirms, in its own way, the revelation that teaches us that all that has begun will have an end."

QUESTIONS FOR THE USE OF SCHOOLS.

CHAPTER I.

Which is the noblest of the sciences?
Mention some of the aims of Astronomy?
Who were the first astronomers?
How far did their knowledge extend?
Who was the greatest astronomer among the ancients?
What did Hipparchus do for Astronomy?
Through whom do we know Hipparchus?
What is the Almagest of Ptolemy?
Did Astronomy flourish among the Arabians?
Who was Regiomontanus?
In what consists the great glory of Copernicus?
What did Copernicus do for Astronomy?
What did Galileo do for Astronomy?
What did Picard do? Descartes? Piazzi? Le Verrier?
What is the scope of Spectrum Analysis?
Who was its great interpreter?
Has Catholic Faith aught to fear from Astronomy?

CHAPTER II.

Where was Copernicus born?
Is there a monument to his memory?
Where did he study?
Where did he receive Holy Orders?
Of what church was he a canon?
What is said of his Observatory?

How many years did he devote to the establishment of his hypothesis?

What is the title of his great work?

At whose instance did he publish it?

Why did he reject the old system of the world?

Explain the old system of the world.

Describe the system of Copernicus.

Were his labors very great?

Give his estimates of the planetary distances from the sun.

Give the present estimates.

How did Copernicus divide his time?

CHAPTER III.

When did Galileo flourish?

What is said of his genius?

What science did he create?

Did he invent the telescope?

Who first pointed it to the heavens?

To whom do we owe the final establishment of the Copernican system?

To whose labors do we owe the modern science of astronomy?

Describe some of the wonders disclosed to Galileo through means of the telescope?

One of the greatest objections to the Copernican system was what?

How did Galileo dissipate it?

What always remained a puzzle to Galileo?

Who solved it?

Explain the question between Galileo and the Inquisition?

Did Galileo always remain a true Catholic?

CHAPTER IV.

What place does Le Verrier occupy as a mathematical astronomer?

What is the law of gravitation?

What must be considered when computing a planet's orbit?
Did the theoretic path of Uranus coincide with its actual one?
How did astronomers account for the discrepancy?
Is it a very difficult problem to find a planet's orbit?
What kindred problem is still more difficult?
How did Le Verrier discover both Neptune and its orbit?
What other great problems in celestial mechanics did Le Verrier solve?
Was he a good Catholic?

CHAPTER V

Was Father Secchi a great student of the sun?
Give an epitome of his views on the radiant orb?
What is said of him as a student of Spectrum Analysis?
Explain the principle of Spectrum Analysis.
Of how many stars did he analyze the spectra?
Describe the four types of stellar spectra.

CHAPTER VI.

When did the Abbot Gassendi flourish?
Who first endeavored to bring comets within the reach of science?
Who first observed a planet's transit across the sun's disk?
Describe Gassendi's method of observing a transit.
What did Piazzi do for Astronomy?
What Picard? What De Vico? Domenico Cassini?
Name other astronomers of Catholic Italy.

CHAPTER VII.

What is Chronology?
What are the two natural units of time measurement?
What causes the troubles in the Calendar?
What is the sidereal day? The solar day?
Does the mean tropical year vary?

What is the sidereal year? What the tropical or solar year?
Who constructed the Julian Calendar?
What is the Julian Calendar?
Give the origin of the Gregorian Calendar.
What is the Gregorian rule?
Is the Gregorian Calendar a great boon?

CHAPTER VIII.

Is Geography an old science?
What will no honest geographer dispute?
What opinion had the ancients concerning the earth's shape?
What is said of Job in connection with geography?
Who was the first real geographer?
Name some other ancient geographers.
When did the great Catholic geographers begin to loom up?
Name some early Catholic geographers.
What did Catholic missionaries do for geography?
Name some Catholic works on geography.
What did Gerard Mercator do for navigation?

CHAPTER IX.

From what sources have we inherited the science of geography?
What is said of Marco Polo as a traveller?
Give an epitome of his travels.
What did he do upon reaching home?
What misfortune befell him?
To whom did he narrate his travels during his captivity?
What is said of Marco Polo's great work, the "Milione"?
What effect did the reading of the "Milione" have on Columbus?

CHAPTER X.

Who was the most illustrious of discoverers?
Where was Columbus born?
Did he early show a taste for the sea?

With how many degrees of the earth's equatorial circumference were the ancients acquainted.

How many degrees were unaccounted for by the ancients?

What motives had Columbus for thinking that new land lay towards the west?

What influences ultimately confirmed him in this view?

Did Columbus follow blind chance in his voyage of discovery?

Describe his struggles in trying to carry out his grand scheme of discovery.

How many voyages did he make to the New World?

What is said of his delineations of the New World?

What did he do for navigation?

Why did Columbus first reach the Bahamas?

Did his great discovery influence intellectual progress?

CHAPTER XI

Who was the first circumnavigator of the globe?

Was he a fervent Catholic?

When did Magellan offer his services to Spain?

What induced Spain to send him forth to circumnavigate the globe?

Describe Magellan's feat of circumnavigation?

What are the Magellanic Clouds?

Why were they so named?

CHAPTER XII.

How does Vasco da Gama rank as a discoverer?

Was the finding of the maritime passage to India of great importance?

Who fitted out Da Gama for his great voyage?

What was the character of Da Gama as a navigator?

Was Da Gama attached to his religion?

Has the name of Vespucci been unjustly aspersed?

When did he offer his services to Spain?

Were they gladly accepted?
How many trips did he make to the New World?
How did it happen that the New World received his name?
What illustrious traveller has cleared Vespucci's name?

CHAPTER XIII.

Who first saw the grand Pacific?
What part of the New World did Balboa first reach?
Where did he next visit?
Describe his journey to the great ocean.
What sad fate did he meet on his return to Darien?
What did Francisco Pizarro achieve in the New World?
What were the achievements of Gonzalo Pizarro?
Who first navigated the Amazon?
Who first saw it?
Who first described it?
What discoveries did Vincent Pinzon make?
What were the achievements of Hernan Cortes in the New World?
Give the names of some distinguished Spanish Catholic discoverers.
What does Irving say of the bold conquistadores?
What great river did Marquette and Joliet explore?
What were the achievements of Fernando De Soto?
Where was his body sunk?
Name other Catholic explorers?

CHAPTER XIV.

Of what does the science of Mechanics treat?
What does it embrace?
What is said of the knowledge of the ancients concerning Mechanics?
To whom are we indebted for our knowledge of the principles of elementary mechanics?
What laws are justly considered the basis of modern mechanical science?

Is it known who first announced the first law of motion?
What laws did Galileo discover?
Who thoroughly verified the mechanical doctrines of Galileo?
What did Galileo do for Hydrostatics?
What did Pascal do? What Castelli? What Torricelli?
What did Father Mersenne do for Mechanics?
Give other Catholic names eminent in Mechanics.

CHAPTER XV.

Of what does the science of Mathematics treat?
How is it divided?
Has applied mathematics a wide range?
With what does pure mathematics deal?
What are classed under the head of pure Mathematics?
What is said of the origin of Arithmetic?
Of what does Algebra treat?
What is said of Geometry?
Who was the greatest of the abstract mathematicians?
What is said of Gaspard Monge in connection with Geometry?
What is said of Michel Chasles as a geometer?
Who invented the Calculus?
What is said of Cauchy as a mathematician?
What of Pascal?
Has the Church any dearth of eminent names in Mathematics?
Give other Catholic names in Mathematics.

CHAPTER XVI.

What is Acoustics?
How is sound produced?
What is the ordinary medium through which sound is conveyed to the organs of hearing?
Do liquids and solids conduct sound?
What is the lowest number of oscillations in a second capable of producing sound?

What the highest?

What is a report? What a tone?

What three characteristics does the ear distinguish in sound?

Can sound be produced in a vacuum?

What is the velocity of sound in air?

At what distance is the human voice ordinarily heard?

Do all sounds move with the same rapidity in the same medium?

What effect has distance on the intensity of sound?

What is the law of the reflection of sound?

Is sound refracted?

What simple laws govern the relation between vibrating strings and musical sounds?

What did the ancients know about sound?

Who laid the foundation of mathematical acoustics?

What did Father Mersenne do for the science?

What did Gassendi do? What Cassini and Picard?

What did Cauchy do?

Did Catholics do their part towards the development of Acoustics?

CHAPTER XVII.

What is Optics?

What did the ancients know about the science?

What are the two theories of light?

Which of these theories is now accepted by physicists?

Does it satisfactorily explain all the phenomena of light?

What is the law of reflection?

What is refraction?

What is the law of refraction?

What is the index of refraction?

What is dispersion?

What is interference?

Upon what does the intensity of light depend?

Upon what its color?

What is the velocity of light?

What is diffraction?

What causes double refraction?
What is polarization?
What is plane polarization? Circular? Elliptical?
What is the greatest name in Optics?
What did Fresnel do for Optics?
What did Biot do? What did Malus do? Fizeau? Grimaldi? Descartes?
What other Catholic names are eminent in Optics?

CHAPTER XVIII.

Of what does the science of Thermotics treat?
What are the two rival hypotheses of heat?
What properties have light and heat in common?
Which hypothesis satisfactorily explains these properties of heat?
What is meant by the conduction of heat?
What is convection?
What is meant by radiation?
By what laws is the reflection of heat governed?
What surfaces absorb heat with greatest facility?
What surfaces reflect best?
By what laws is the refraction of heat governed?
What is one of the most notable as well as general effects of heat?
What is a Thermometer?
What is specific heat?
What is latent heat?
What is the great name in Thermotics?
What did Fourier do for Thermotics?
What did Melloni do? What Dulong and Petit?
What did Regnault do? Mariotte? Sanctorius?
Mention some other great Catholic names in Thermotics?

CHAPTER XIX.

What is the oldest form of Electricity?
Who gave Magnetism its name?

Where is the first mention of the electric property found?

Who coined the word electricity?

When did Franklin announce the results of his experiments in Electricity?

What did Coulomb do with his torsion-balance?

What was Galvani's great experiment?

What did Volta do for Electricity? What did Oersted discover?

What did Ampère discover? What Faraday?

When was the telegraph invented?

Who invented the greatest of dynamos?

Who invented the storage-battery?

What has commerce done with the thunderbolt?

CHAPTER XX.

What did the labors of Galvani and Volta furnish?

What is galvanic electricity also called?

What kind of electricity is employed in telegraphic communication?

What is a galvanic battery?

Name some of the principal batteries.

What is the principle of telegraphy?

From what great experiment do the wonderful uses of electricity in modern commerce date?

Who became especially interested in the work of Galvani?

What did Volta do for Electricity?

To what two Catholic scientists do we in great part owe the science of Galvanism?

CHAPTER XXI.

What two Catholic scientists established the laws of Electricity?

What did Coulomb do for Electricity?

Describe the torsion-balance electrometer?

What two laws governing the attraction and repulsion of

electrified bodies did Coulomb demonstrate by means of this instrument?

Describe other labors of Coulomb in behalf of Electricity.

What is said of Ampère?

Give a synopsis of what he did for Electricity.

What is Ampère's theory of the earth's magnetism?

What is Ampère's formula for determining the movements of the magnetic needle under the influence of the electric current?

CHAPTER XXII.

What is Electro-magnetism?

What is Magneto-electricity?

What is a Dynamo?

Describe the Gramme dynamo?

In what does its superiority over all other dynamos consist?

What is considered the greatest scientific discovery of the last half hundred years?

Was the storage of electricity a great discovery?

What is meant by electric storage?

What is a storage-battery?

Who made the first storage-battery?

Describe Gaston Planté's storage-battery?

How does the storage-battery work?

For what are we indebted to the two Catholic gentlemen Gramme and Planté?

CHAPTER XXIII.

What did the great Catholic physicist Biot do for Electricity?

What did the immortal Descartes do?

Who first observed the electric spark from a living body?

What did Abbé Caselli do for Electricity?

Who invented the Pantelegraph?

What is the Pantelegraph?

What did Leon Foucault do for Electricity?

Who invented the first electric lamp?

Describe Foucault's lamp.

Who was the first and most famous manufacturer of Carbons for electric lamps?

What department of electricity did the Catholic physicist Nobili improve?

Name other great Catholic electricians.

CHAPTER XXIV.

Had the Egyptians a fair knowledge of Chemistry?

Were the Chinese early acquainted with many chemical facts?

When did the Arabians begin to study Chemistry?

What was the origin of European Alchemy?

What was the two-fold aim of Alchemy?

Were there two classes in Alchemy?

What is the domain of Chemistry?

Explain the phlogistic theory.

Explain the Lavoisierian or Oxygen theory.

What is the Atomic Theory?

What four laws govern the proportions in which elements combine?

What is Electro-chemistry?

Is Chemistry in a transitional state at present?

To what is this owing?

CHAPTER XXV.

Who is the father of modern Chemistry?

When was Lavoisier born?

Is Chemistry greatly indebted to him?

What was one of his greatest merits?

Who introduced the balance into Chemistry?

How did Lavoisier disprove the theory of Phlogiston?

Describe the experiment in which he showed that the increase of weight in an oxidized metal is due to its absorption of gas.

Did Lavoisier regard some elements as simple?

Did he originate the method still in use of decomposing organic substances?

Explain the nomenclature founded on the Oxygen Theory?

What tribute does Whewell pay the greatest of chemists?

CHAPTER XXVI.

What was the belief of the alchemists regarding the composition of metals?

To what did this belief lead?

Is the Chemistry of to-day going back to Alchemy?

Are the alchemists deserving of the gratitude of mankind?

Mention some of the great alchemists?

How does Van Helmont rank among early chemists?

What country has done most for the philosophy of chemistry?

Have most of the great French chemists been children of the Church?

What did Dumas do for Chemistry?

What did Antoine César Becquerel do?

What did Dulong and Petit do?

What did Michel Eugene Chevreul do?

What anecdote is related of him showing his devotion to the Mother of God?

Is Chemistry particularly rich in great Catholic names?

CHAPTER XXVII.

What is Mineralogy?

To what is the science confined?

What are the two schools of classification in Mineralogy?

Is it difficult to classify minerals on chemical grounds?

What external character of minerals is the most marked?

What does Haüy assume as the principle of Crystallography?

Give some exceptions to Haüy's rule.

What is a Crystal?

What is Crystallography?

Give the three principal processes of crystallizing?

Give the six geometrical classes to which all crystalline forms may be reduced.

Give the six fundamental forms of crystals.

Give an illustration of each form.

What is the greatest name in Mineralogy?

What did Haüy do for Mineralogy?

What tribute does Whewell pay him?

CHAPTER XXVIII.

Of what does Botany treat?

Has the science a vast domain?

What three great names does Botany claim among the ancients?

What three great names does the modern science claim?

Who is the father of modern Botany?

What did Caesalpinus do for Botany?

What is the system of Linnæus called?

Explain the Linnæan system.

What is considered in the natural system?

Who were the authors of the natural system?

What did the Jussieus do for Botany?

What does Whewell say of the Jussieuan system?

Name two great Catholic botanists lately deceased?

What tribute does Dr. Vidal pay to Louis René Tulasne?

CHAPTER XXIX.

Of what does Physiology treat?

How is the word derived?

Is the science one of vastness and complexity?

What three names reached great fame in this science among the ancients?

Who among the ancients was the greatest master of the science?

What did Galen know about the animal frame?

Who first called Galen seriously in question?

Who was Vesalius?

What three Catholic professors were the founders of modern anatomical science?

What did Fallopius do for anatomy?

What Eustachius? What Realdus Columbus? What did Caesalpinus do?

Whose is the greatest name in modern anatomy?

From whom did Harvey receive his tuition?

What did Spallanzani do for Physiology?

What did Malpighi do?

What did Santorini do? What Bichat? Johannes Müller?

Give some other Catholic names of distinction in Anatomy and Physiology.

Why does Zoology come under the head of Physiology?

Was any attempt made to classify zoology artificially?

What did Cuvier do for Zoology?

What does Whewell demonstrate in reference to the belief of great discoverers?

What two great Catholic names in Zoology come immediately after Cuvier's?

CHAPTER XXX.

To what degree of development has Geology reached?

What brought Geology into disrepute?

What is Geology?

How are the rocky strata of the earth divided?

How do lithologists read the chronological order of the earth?

What is Lithology?

How do paleontologists read this order of creation?

What is Paleontology?

Which has kept the best record?

What is a fossil?

What country is the birthplace of Geology?

Who was among the very first to form a correct opinion of fossils?

Who succeeded Leonardo da Vinci?

What opinion had Colonna of fossil-shells?

What did Steno do for Geology? What Scilla? What Vallisneri?

By whom was Vallisneri succeeded?

What position have Italians always held in Geology?

Give some well known Catholic names in Geology?

Epitomize the controversy concerning the theory of central igneous fluidity?

What has become of the quondam conflict between Geology and the Cosmogony of Moses?

Give the epitome of Geology taken from Sorignet's Sacred Cosmogony.

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